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TECHNICAL REPORT REMR-CS-5

INSTRUMENTATION AUTOMATION FOR CONCRETE STRUCTURES

Report 4

DEMONSTRATION OF INSTRUMENTATION AUTOMATION TECHNIQUES AT BEAVER DAM, EUREKA SPRINGS, ARKANSAS

by

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The instrumentation automation system at Beaver Dam in northwest Arkansas is presented in this fourth of a series of Repair, Evaluation, Maintenance, and Rehabilitation (REMR) reports entitled "Instrumentation Automation for Concrete Structures." As a demonstration installation of the instruments, computer hardware, computer software, and the techniques used, this program is an integral part of the REMR work unit aimed at improving instrumentation for older concrete structures.

Improvement of data acquisition instrumentation and implementation of the benefits of these improvements was the primary goal of this project. Stemming from this research, a most important element in the chain of data acquisition is the user's ability to understand and grasp the new technology. The user must be capable of applying these strides in technology toward improving productivity, data quality, and the safety of our concrete structures.

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PREFACE

The demonstration project reported herein was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), under Civil Works Research Work Unit 32309, "Improved Instrumentation for Older Concrete Structures." Mr. Edward F. O'Neil is Principal Investigator of this work unit, a part of the Concrete and Steel Structures Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program sponsored by HQUSACE. The Overview Committee at HQUSACE for the REMR Research Program consists of Mr. James E. Crews and Dr. Tony C. Liu. Technical Monitor for this study was Dr. Liu. Mr. Jesse A. Pfeiffer, Jr., is the REMR Coordinator for the Directorate of Research and Development, HQUSACE.

Report 4 of a series entitled "Instrumentation Automation for Concrete Structures" describes a demonstration installation of an instrumentation automation system at Beaver Dam in northwest Arkansas. The report describes instruments, computer hardware, computer software, and the installation techniques used during this demonstration. This report is a part of the overall transfer of automation technology that was gained during the conduct of this work unit. It is part of a series of reports describing the process of instrumentation automation and the hardware and software available to accomplish this task.

The demonstration was conducted at Beaver Dam, Eureka Springs, AR, which is under the supervision of US Army Engineer District (USAED), Little Rock. The sensors and electronic equipment used in this demonstration were installed by Mr. Donnie Ainsworth, Mr. Larry Crittenden, and Mr. O'Neil, all of the US Army Engineer Waterways Experiment Station (WES). Mr. Steve Hartung, Mr. Charles Deaver, and Mr. Harlan Petter, all of the USAED, Little Rock, and Mr. Lynn Carpenter, of the US Department of the Interior, Bureau of Reclamation, assisted in the successful conduct of the demonstration.

The preparation of this report was conducted at WES under the general supervision of Mr. Bryant Mather, Chief, Structures Laboratory (SL), Mr. John Scanlon, former Chief, Concrete Technology Division (CTD), Mr. Kenneth Saucier, present Chief, CTD, and under the direct supervision of Mr. Henry Thornton, Chief, Evaluation and Monitoring Unit, (E&MU). The report was prepared by Mr. O'Neil, Research Civil Engineer, E&MU. Problem Area Leader for Concrete and Steel Structures is Mr. James E. McDonald, CTD. Program Manager for the

REMR Research Program is Mr. William F. McCleese, CTD. This report was edited for publication by Mmes. Gilda Miller and Chris Habeeb, Editor and Editorial Assistant, respectively, Information Products Division, Information Technology Laboratory, WES.

COL Dwayne G. Lee, EN, was Commander and Director of WES during the publication of this report. Dr. Robert W. Whalin was Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
Fahrenheit degrees	5/9	Celsius degrees or kelvins*
feet	0.3048	metres
inches	25.4	millimetres
miles (US statute)	1.609347	kilometres
pounds (force) per square inch	0.006894757	megapascals
square inches	6.4516	square centimetres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

INSTRUMENTATION AUTOMATION FOR CONCRETE STRUCTURES

DEMONSTRATION OF INSTRUMENTATION AUTOMATION TECHNIQUES AT BEAVER DAM, EUREKA SPRINGS, ARKANSAS

PART I: INTRODUCTION

Background

1. The instrumentation automation demonstration program is an integral part of the efforts under the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) work unit* aimed at improving instrumentation for older concrete structures. The overall objective of the work unit is to improve the Corp's ability to collect safety related data from the many structures under its control. Central to this objective, is the technology that has evolved allowing computers to automatically collect and process data from civil engineering instruments. In recent years, this technology has developed to the point where the costs to install or retrofit the necessary equipment are now affordable and, in most cases, are more economical and faster than collecting the same data by hand. For these reasons, it is to the advantage of the Corps to understand and use these capabilities to their fullest extent.

2. A primary milestone of the work unit was the generation of three REMR reports (Lindsey et al.,** Keeter et al.,† Currier and Fenn††) which were written to aid instrumentation personnel in becoming familiar with this new technology. The first of these three reports is a text on instrumentation automation describing the necessary components and design steps to assemble an

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* REMR work unit 32309, "Improved Instrumentation for Older Concrete Structures."

** J. Lindsey, D. Edwards, A. Keeter, T. Payne, and R. Malloy. 1986. "Instrumentation Automation for Concrete Structures; Instrumentation Automation Techniques," Technical Report REMR-CS-5, Report 1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

† A. Keeter, B. Stonecypher, T. Payne, M. Skerl, J. Burton, and J. Jennings. 1986. "Instrumentation Automation for Concrete Structures; Automation Hardware and Retrofitting Techniques," Technical Report REMR-CS-5, Report 2, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

†† R. Currier and M. Fenn. 1986. "Instrumentation Automation for Concrete Structures; Available Data Collection and Reduction Software," Technical Report REMR-CS-5, Report 3, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

automated data acquisition system. The second report describes how to retrofit existing instruments so that they may be read automatically. Also contained in the second report are comparative descriptions of available instruments and computer hardware to help the user make the proper choice in selecting the equipment for a proposed system. The third report is similar to the available instrument portion of the second, except that it details available software to drive the automated computer hardware, reduce and analyze the data, and report it in a fashion usable by the engineering community.

3. The demonstration program described in this fourth report of the series represents the second major milestone in improving the Corps' instrumentation monitoring capability. It provides for the installation of an automated monitoring system to collect safety related data on concrete structures, thereby demonstrating and reinforcing the theory described in the above mentioned reports.

Purpose

4. The purpose of this demonstration program is to supplement the information provided in the set of reports on automation, as well as to provide an opportunity to describe how a particular installation was handled, and how the instruments performed. By providing an actual field installation to reinforce the written techniques, the instrumentation community will have a better understanding of the process of instrumentation automation, and therefore be more familiar with its time and labor-saving capabilities.

Scope

5. The demonstration program covers the discussion of the types of data which were selected for automated collection; a description of the automation system as a whole; a description of the instruments used, and how they fit into the overall system; as well as a comparison of the automated method of data collection with that of the previous method used. The scope also covers the descriptions and comparisons of two automated plumbline monitoring systems which were installed and tested during the demonstration program.

6. The demonstration program, as a formal event, will remain in effect for a 1-year period commencing in January 1988. During that time the data

collected will be analyzed, and the automated methods will be compared to the previous manual methods of collection. During and subsequent to the demonstration, those who are involved with instrumentation are encouraged to visit the demonstration site and inspect the sensors, computer hardware, and the software.

Instrumentation background

7. The site of the demonstration project is Beaver Dam. Beaver Dam is located on the main stem of the White River in northwestern Arkansas, 9 river miles upstream from the town of Eureka Springs, Arkansas (Figure 1). The project consists of a multipurpose concrete gravity dam, 228 ft* high and 1,333 ft long, connected with an earth embankment dam, 1,242 ft long. The dam impounds a reservoir 15 miles long. Two generating units in the powerhouse generate 112,000 kW of power for residents of Arkansas, Missouri, Oklahoma, Louisiana, and eastern Texas. Construction of the dam began in November 1960 and was completed in June 1966. Normal full pool is at el 1,120 ft, mean sea level (MSL).

8. The plan and elevations of the dam are shown in Figure 2. The concrete portion of the dam is a straight, gravity dam. There are two internal galleries which run parallel to the longitudinal axis of the dam. The inspection gallery extends from monolith 1 to monolith 27 and follows the contour of the foundation across the dam. The operating gallery, located at el** 955 ft MSL, extends from monolith 12 to monolith 23, where it meets the inspection gallery. This gallery is essentially horizontal.

9. The instrumentation installed at the dam prior to the demonstration project consisted of standpipe-type uplift pressure cells to monitor foundation uplift pressure, V-notch weirs to monitor gallery flow, monolith tilt and deflection instruments, lakestage and tailwater gages, and measurement of active cracks in the concrete. All of these instrumentation tasks, with the exception of the lakestage and tailwater elevations, had been monitored by manual methods.

10. The US Army Engineer District, Little Rock, has automated the reading of approximately 84 piezometer wells on the main embankment and several dikes of the reservoir. The automation system they procured to accomplish

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 4.

** All elevations (el) cited herein are in feet referred to National Geodetic Vertical Datum (NGVD) of 1929.

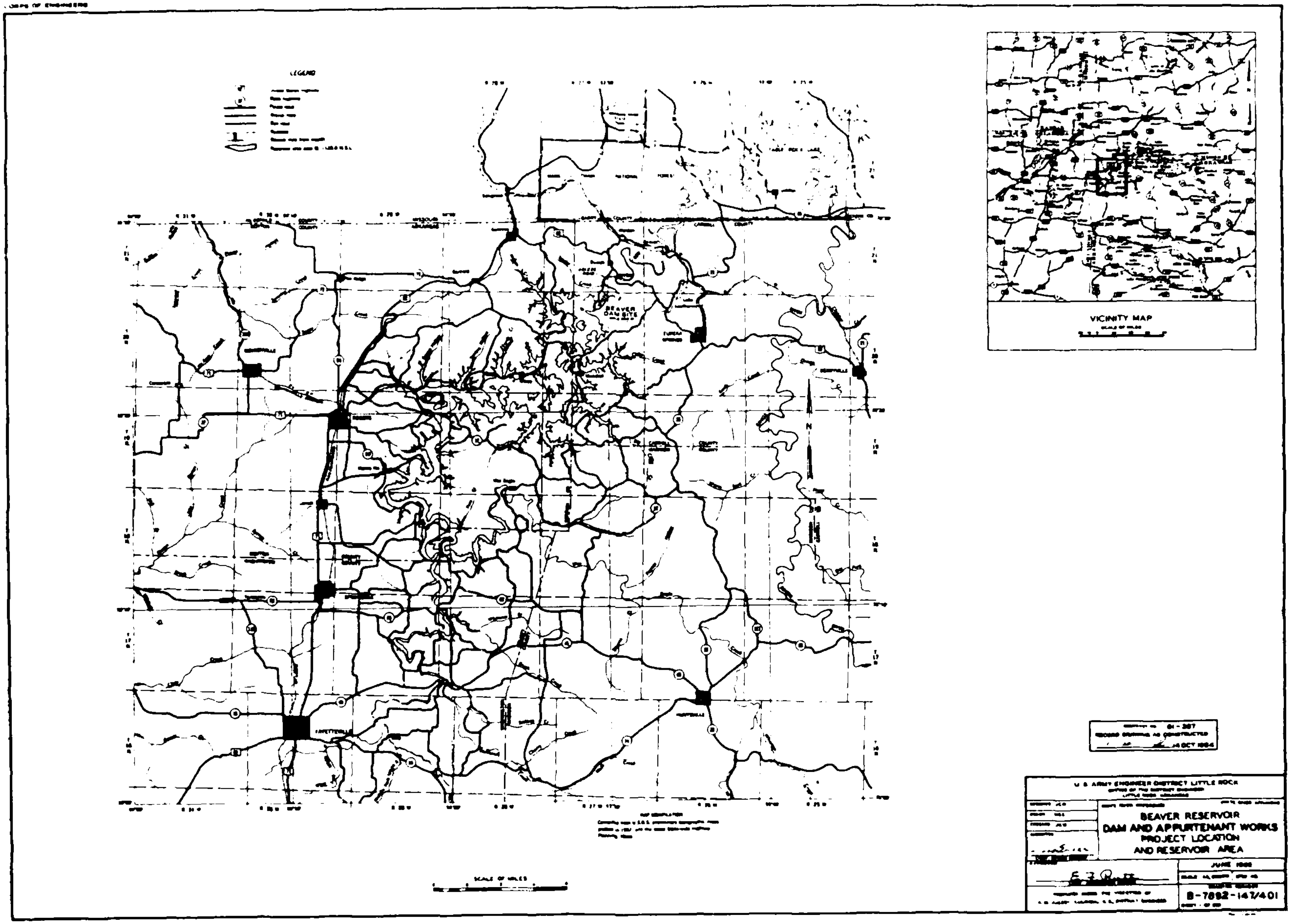

Figure 1. Vicinity map of Beaver Dam and Reservoir

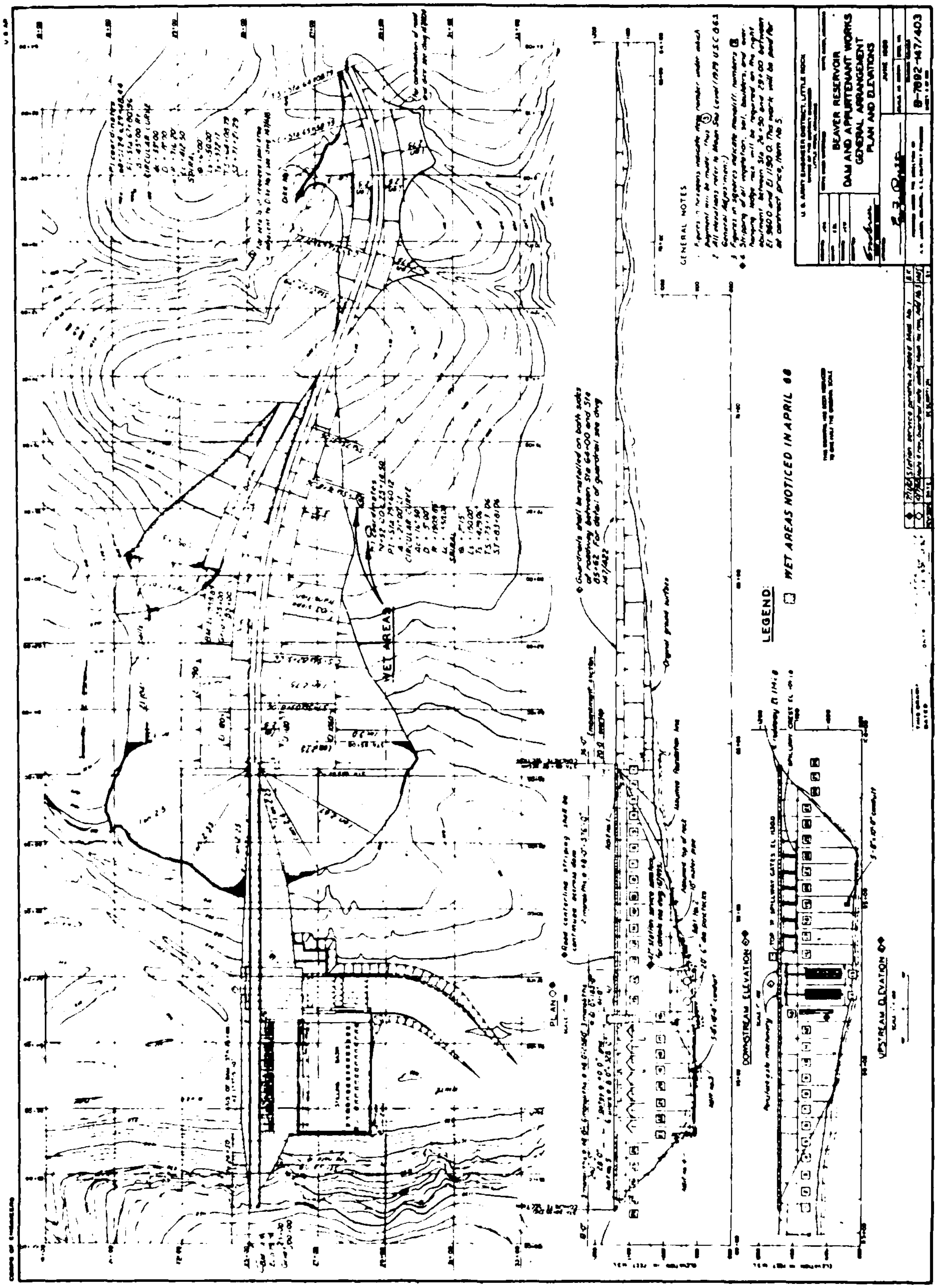

Figure 2. Plan and elevation of Beaver Dam

this task was also chosen to be the control system for the demonstration program described in this report. The compatibility between systems was very desirable, as it would greatly affect economy and diversity of measurement capability. Throughout this report, mention will be made of the sensors in the embankment and dike inclusion as a part of this report is appropriate in the interests of complete description of system capabilities.

Layout of the dam

11. The major access galleries and passages within the dam are shown in plan and elevation view in Figure 3. This figure also shows the major adits and vertical access shafts within the dam.

12. The inspection gallery is typically 6 ft wide by 8 ft tall, with drainage gutters located on one or both sides of the passage. The operating gallery has the same height, but the width varies from 5 ft to 6 ft 6 in. In the inspection gallery, there are two sizes of drainage gutter. On one side of the gallery the gutters are typically 6 in. deep, 15 in. wide at the base, and 18 in. wide at the top. On the opposite side of the gallery the gutters are 6 in. deep, 4 in. wide at the base, and 6 in. wide at the top. The gutters in the operating gallery are 11 in. wide and 12 in. deep. They are drained into the gutters in the inspection gallery through 4-in.-diam pipes.

13. The majority of the installed instruments terminate in these galleries. All the uplift pressure cells, the weirs, and joint meters installed in the dam are located either directly on the galleries or in rooms off of these galleries. The lakestage and tailwater equipment is located in the powerhouse.

14. There are several vertical shafts shown in Figure 3, as well as a main elevator shaft located in monolith 16 running from the inspection gallery up to the top of the dam. These shafts provide vertical movement of utilities and electrical wiring, and the elevator shafts provide vertical transportation to and from the top of the dam.

15. The central location for monitoring instrumentation data at Beaver Dam is in the powerhouse located below the dam adjacent to the spillway. Pool elevation and tailwater elevation measurements are available here.

16. The main embankment of the dam and two dikes on the reservoir house 84 vibrating wire pressure transducers used to monitor water elevation in piezometer wells. These instruments are distributed as follows: 25 to the main embankment, 44 to dike 1, and 15 to dike 3. These instruments monitor

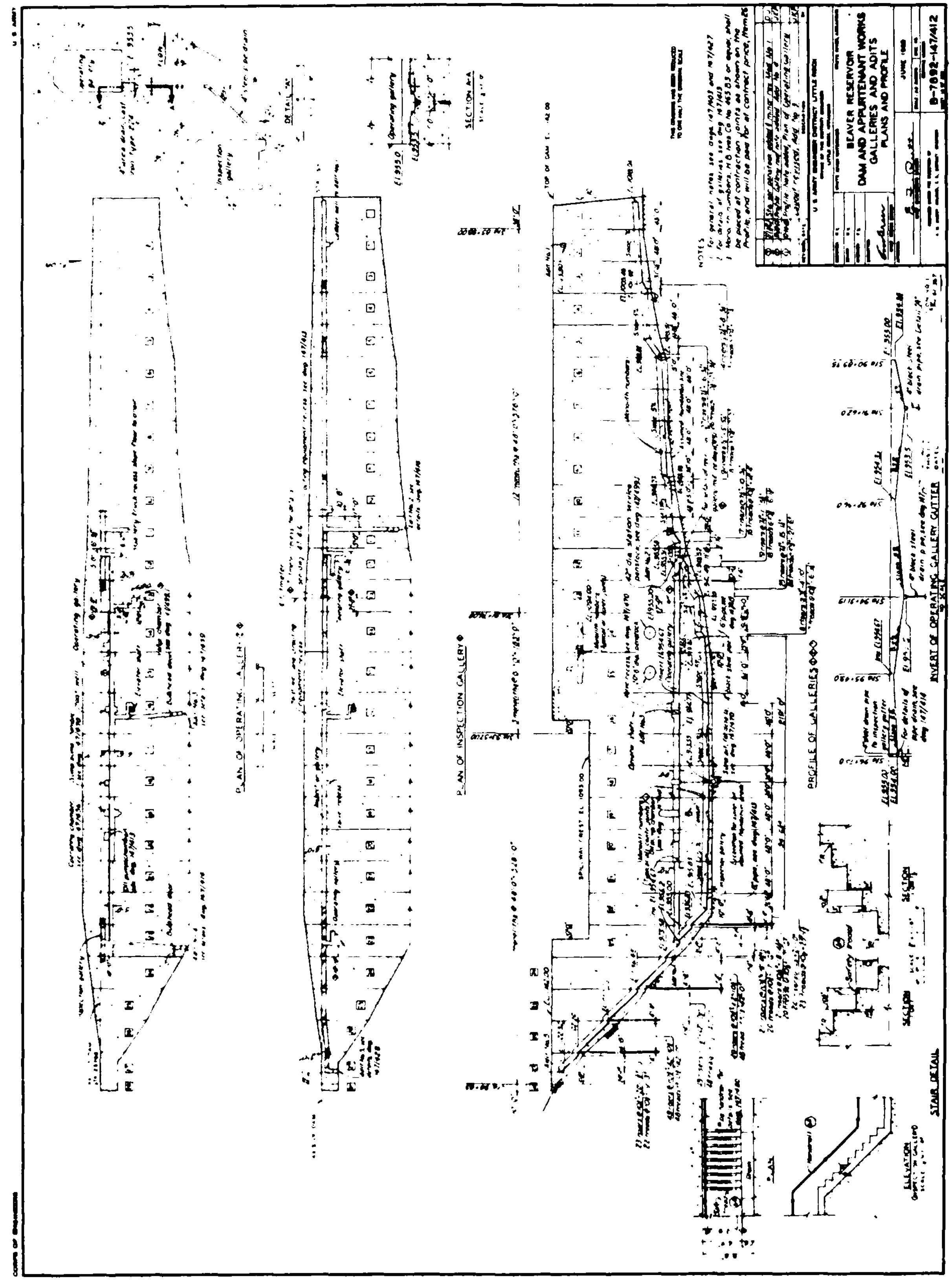

Figure 3. Plan and elevation of the dam galleries

the flow path of ground water in the embankment and dikes, and warn of any major change of ground-water elevation.

Capabilities of instumentation

17. A main goal of the instrumentation program was to demonstrate the capabilities of computers and data acquisition equipment for automating the tasks of collecting and reporting safety data on a regular basis. For these reasons, the instruments and procedures which were automated were chosen to demonstrate a variety of automating techniques and capabilities.

18. All of the instruments which were automated under this program had been previously monitored by manual means. It was the intentions of the program to demonstrate new automation techniques and avoid duplicating any previously automated instrumentation. The types of measurements automated under the demonstration program are uplift pressure measurement, flow over weirs, crack movement, and lakestage and tailwater elevations and are described in paragraphs 19 through 22.

19. Uplift pressure measurement. There are three monoliths at Beaver Dam which contain uplift pressure cells. Two of these monoliths are within the spillway portion of the dam (monoliths 18 and 20), and the remaining one (monolith 14) is a penstock monolith. The uplift cells are the standard standpipe type. Each of the three monoliths contain seven of these cells evenly spaced from downstream to upstream along the monolith center line as shown in Figure 4. Their reading cutouts are located in the inspection gallery in the same monoliths as the respective uplift cells. The 1-1/2-in.-diam uplift pipes are capped with a 1-1/2-in. galvanized pipe cap with a 3/8-in. adapter to fit a hydraulic pressure gage. Under the demonstration program, these pressure gages are connected to a scanning pressure valve which can read the pressures from as many as 48 pressure cells registering positive uplift pressure and report the results to a central data acquisition system.

20. Flow over weirs. Much of the leakage in the dam comes from foundation drains, crack drains, and leakage from joints. Prior to the demonstration, there were two methods of monitoring how much water passed through the dam and into the sump. The overall water flow entering the dam was measured by monitoring how often the sump in the base of monolith 18 (see the elevation in Figure 2) was pumped. Knowing the volume of water pumped from the sump, and how often it was pumped, provided a record of overall flow. This method did not tell where the flow was coming from, only the value. Weirs were

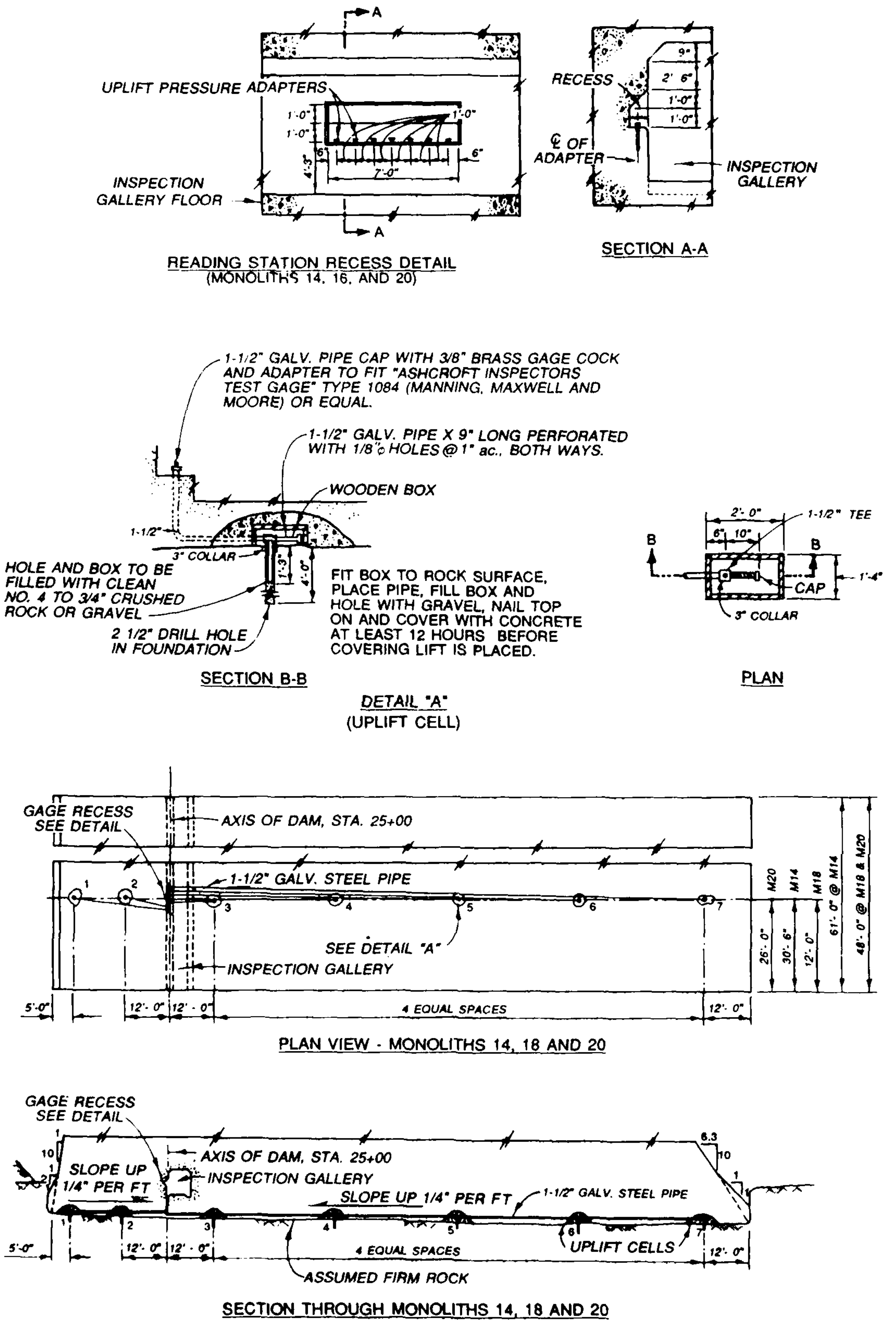

Figure 4. Plan, section, and details of the uplift pressure cells

installed at several locations in the gutters of the inspection and operating galleries. These weirs were read by observing where the water level behind the weir struck a plate calibrated in inches of water. This method would identify rates of flow from different areas of the dam, however the method required manual reading of each weir and was subject to error due to the awkward angle that the gage had to be read.* The second method used consisted of monitoring a particular drain by collecting the water in a container of known volume and using a stopwatch to monitor the time. This method is adequate, but very labor intensive. Under the demonstration, nine new weirs were installed at critical locations in the gallery gutters. Submersible, hydraulic pressure transducers were installed behind these weirs to monitor the height of water behind the weirs, and hence the flow over the weirs.

21. Crack movement. There are two cracks in monoliths at Beaver Dam which the dam personnel are interested in monitoring. Prior to the demonstration, these cracks were monitored by measuring the movement of two studs anchored on either side of the crack. During the demonstration, these cracks were each fitted with two Carlson joint meters mounted across the crack. Both meters were oriented at a known angle to each other with one meter sloping upwards and the other sloping downwards. This installation of joint meters allowed the horizontal and vertical components of crack movement to be calculated from the measured strain in the meters. The previous method required manual reading and would only give horizontal crack movement.

22. Pool elevation measurement. The lake stage and tailwater elevations are valuable in the calculation of uplift pressures, the regulation of water allowed over the spillway, free surface of water in the embankments, and several other useful structural measurements. Prior to the demonstration, these elevations were automatically monitored, but their output was recorded on strip chart paper and displayed on the main control board in the powerhouse. During the demonstration, these elevations were further automated by the installation of an additional water level encoding instrument and sending its output signal to the data acquisition system.

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* Since the plates for reading the height of water behind the weirs were located in the water in the gutters, the inspector's line-of-sight had to be near the water level. The gutters are lower than the gallery walkway, and the entire area is poorly lit, making manual reading difficult and less accurate than reading by pressure transducer.

PART II: SYSTEM DESCRIPTIONS

Overall System Design

23. The overall data acquisition and collection system for the Beaver Dam demonstration were chosen using principles described in Report 1 of the series, "Instrumentation Automation for Concrete Structures" (Lindsey*). This report details criteria to consider which will help ensure that the chosen system is the right size for the automation chore in question and that it can accomplish the measurement tasks for which it was designed. These criteria include functional, environmental and system considerations, sensor choices, signal considerations, input and output needs and data processing, reduction, and display considerations. Following a methodology such as prescribed in that text will ensure that all appropriate facets of system configuration have been considered and the resulting system is appropriate for the need.

System architecture

24. The system architecture was the first of these considerations. The choices were a centralized or a distributed system. In a centralized system, all control of the instruments reside at a central controller. This architectural choice is simple, because it minimizes the electronics of the system. The alternative is a distributed system, in which data collection and processing tasks are delegated to intelligent remote controllers, and the remotely processed data are transmitted to the central controller. The central controller then takes care of chores such as managing the control of the intelligent remote controllers and the tasks of further reduction and distribution of the collected data. The latter choice is more complicated, but generally correct when the data collection chore is large.

25. While it is preferable to choose a centralized system to keep the architecture as simple as possible, considerations of size, cost, and expansion capability dictated the use of a distributed system at Beaver. The sensors are widely distributed over the dam, both in the concrete and earth-fill sections, and the cost of wire to transmit signals from each instrument to a central controller greatly outweighed the cost of adopting a distributed architecture. The sensors in the dam were hard-wired to an intelligent remote

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* Op. cit.

controller called a measurement and control unit (MCU) centrally located within the dam, and the link from the MCU to the central controller was accomplished with a shielded, twisted pair of wires. The link between the dike and embankment sensors with the controller in the powerhouse was accomplished via radio transmission, since the cost of hard-wiring and trenching would have been many times more expensive.

Expandability

26. The advantages of expandability were also in the favor of a distributed system. With a central system, the number of input/output (I/O) interface slots available in a centralized system were limited to those supplied with the system. A number of these slots must be occupied by circuit boards which handle the task of collecting and processing the sensor data. Depending on the number and type of sensors being monitored, these slots will fill up quickly. With a distributed system, on the other hand, the MCU's provide their own I/O interface slots, and the central controller does not become populated with data collection and processing hardware. This leaves the central controller slots free to take more memory, specialized cards such as graphics cards, modem cards, or numeric coprocessors to speed operation of the system. The number of I/O slots in the MCU can also be chosen to allow for additional system expansion for the future.

System reliability

27. Criticality. The importance of the data being monitored will dictate the degree of system reliability. The more critical a measurement is, the more reliable the monitoring system should be. The instruments being monitored under this demonstration project are all safety related instruments, and as such should be afforded a high degree of system reliability.

28. The instrumentation and equipment chosen use state-of-the-art electronics to take advantage of the recent developments in quality standards and engineering reliability of their circuitry. While state-of-the-art equipment may cost more at the outset, the system reliability will be increased, and overall life data costs will be lower.

29. System complexity. The distribution architectural type of system chosen is more complex. As a result, it presents more areas where problems can occur. Generally speaking, a simple system or one of minimal complexity will reduce system problems and increase overall reliability. However, in this case, considerations of cost and expandability made the choice of

distributed architecture the correct one. As will be described later, even though the system composition is distributed in nature, the design has been kept as simple as possible for the task to be accomplished.

30. Environmental conditions. The environment in which the components operate will have a decided effect on the reliability of the system. If the environment is extremely harsh, the longevity of a system will be reduced where precautions are not taken to protect the components. In a combination concrete and earth embankment dam such as Beaver Dam, the environmental conditions can vary widely. While the temperature extremes in the concrete section are not severe (generally ranging from 10 to 18° C), the temperatures on the surface of the earth embankment portion can range from -26° to 39° C. In the concrete portion of the dam, the air is often damp, and there is always water running in the gutters of the galleries. Out on the earth embankment, any instrumentation is subjected to the full extremes of northwest Arkansas weather, ranging from snow in the winter to heavy rains in the spring and early summer. These conditions warrant environmental protection to preserve the components of the instrumentation system.

31. Several environmental precautions have been taken in the Beaver Dam installation. The MCU installed in the dam has been placed in an environmental cabinet which protects it from moisture, dirt, and dust in the air. The three MCU's which are installed in the earth embankment and dikes are buried in the embankment in fiberglass enclosures which have a hatch-opening type top for access, a sand base, and French drain in the base to drain off any water which may enter the box. Within these enclosures, the MCU's themselves are housed in National Electrical Manufacturers Association (NEMA) enclosures to protect the electronics from moisture, humidity, and extreme temperatures.

32. The hydraulic pressure transducers, which were installed in the earth embankment, are all housed in the piezometer tubes. The wiring from these instruments extends from the sensor up the length of the piezometer tubes and is buried in the earth, between the tube and the closest MCU. The signal is radio transmitted from that MCU to the central controller, called a network monitoring system (NMS) in the powerhouse. Those instruments which were installed in the concrete portion of the dam, were wired to the MCU in the dam. Their cables were protected by running them along conduit to protect

them from physical abuse, and in instances where the cable could be damaged from impact, it was drawn through metal conduit for protection.

33. Ease of use. Several design features were incorporated into the overall system, mainly in the software which runs the system, to make it easy to use. Running the system by means of menu driven screens and the ability to run the system remotely are two such features. Menu-driven software is a philosophy that always provides some avenue for the user to take. He or she is given a menu to choose from and always knows what kind of input is expected. Software that asks for the next command, assuming that the user is familiar with the list of appropriate commands, does not provide for the new or casual user of the system. These types of systems are hard to use and difficult to remember. Remote use of the system also allows for ease of use. The extra steps it takes to provide a system that can be accessed from a district office or from a remote terminal away from the system controller shows concern for the user who must interact with the machinery. These features are discussed in detail beginning at paragraph 97.

34. Maintenance. Keeping any instrumentation automation system running properly requires maintenance. The maintenance philosophy chosen for a particular system will depend upon the system and the capabilities of the people charged with caring for it. If the personnel do not have extensive training in electronic repair, or the size of the staff is small, then perhaps a philosophy of purchased maintenance and repair would be the most effective means of keeping the system running. If, on the other hand, the amount of equipment is large, and the technical staff is well versed in repair techniques, then any maintenance chore can be accomplished in-house, saving time, money, and inconvenience. The majority of situations will require some combination of the above two extremes. There will be an amount of maintenance and repair which in-house personnel can do, and the major repair duties will be contracted, either through repair teams coming to the project, or the equipment being sent away for the repair.

35. The data acquisition system chosen for the Beaver Dam demonstration consists of components which are mounted on a fixed main circuit board and supplemental printed circuit boards mounted in I/O slots connected to the main printed circuit board. The instrumentation staff at Beaver is capable of performing some of their own repair, but the staff is small. Those maintenance

tasks which can be performed by swapping out a printed circuit board are performed in-house, and the difficult maintenance tasks are performed by contract. The system was supplemented with a general maintenance contract which will provide for repair of parts and components by the system manufacturer in the event that the system malfunctions. In addition, the requirement for a set of general maintenance tasks which are to be performed on the instrumentation were written into the operation manual. This allows the in-house personnel to conduct some of their own preventive maintenance. Both of these features were incorporated to extend the operating life of the system and to provide for greater system reliability.

Component Description

36. A schematic representation of the overall system is shown in Figure 5. There are five MCU's at the dam. Three are buried in the embankment and dikes of the dam to collect data on piezometers. One MCU is located in the concrete portion of the dam to collect data on safety related measurements there. The last MCU is located in the powerhouse and acts as a central receiver of the data collected at the other four MCU's, as well as handling several channels of sensor data. This figure shows the system components, and diagrams their relationship with each other. These components will be described in the following paragraphs.

Measurement and control units

37. The five units labeled MCU in the upper half of the figure are the measurement and control units. These units are the system's main data acquisition and control centers. The MCU main functions are as follows:

- a. Take all measurements from the sensors, compute all calculations on these measurements, and control all functions of the MCU according to parameters, schedules, and sequences defined by the user.
- b. Communicate these measurements and calculations to the NMS or other designated logging unit according to schedules defined by the user.
- c. Monitor the sensor measurements and compare them to user set alarm limits, and convey alarm conditions of sensors to the NMS or designated logging unit. The MCU also determines that a sensor is truly in an alarm state by reading the sensor multiple times and confirming an alarm condition before announcing it to the NMS.

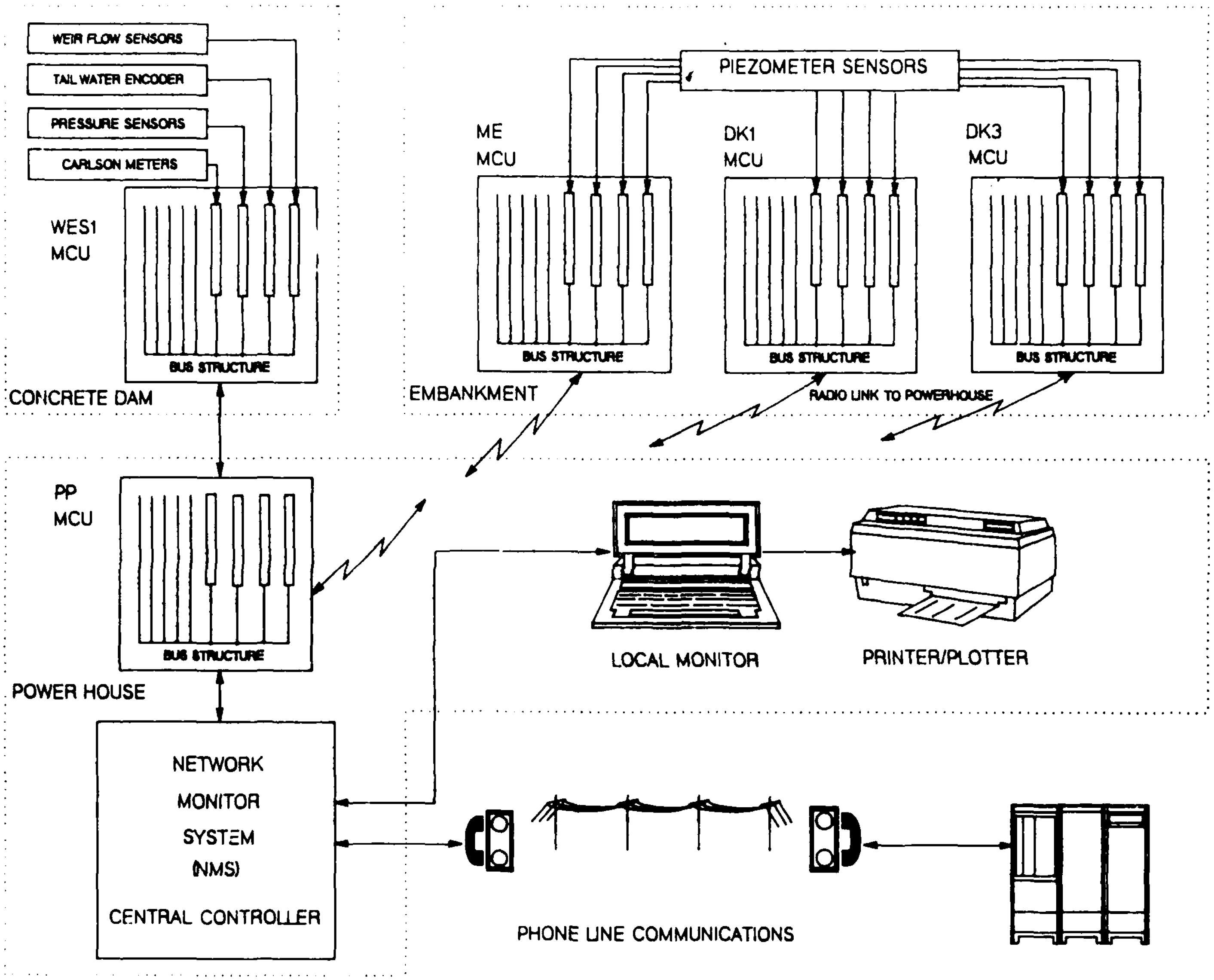


Figure 5. Schematic representation of the overall data acquisition system at Beaver Dam

d. Store sensor measurements in a buffer memory to prevent their loss if the network is not functioning properly.

e. Manage the use of power on the MCU and monitor the status of its internal batteries.

f. Store setup information in nonvolatile memory and use this information to restart the system after a power failure or planned system shutdown.

38. All system sensors are connected to the MCU's by means of terminal connectors located on the senor interface cards which plug into one of the bus structures of the MCU's. There are different types of interface cards for different types of sensors. For instance, the three MCU's which are devoted to collecting data from the piezometers in the embankment portions of the dam (labeled "ME," "DK1," and "DK3") have interface cards which measure changes in output-signal frequency to indicate changes in the elevation of water in the piezometer tube. The MCU which is located in the concrete portion of the dam (labeled "WES1" in Figure 5) contains several different sensor interface cards. One is designed to read the change in loop current for measuring the flow of water over weirs. A second card is designed to read resistance data from Carlson type sensors for measuring crack movement. A special card which will accept binary coded decimal (BCD) information from a specialized scanning pressure sensor has been installed as well as a fourth card which reads information from a digital encoder for measuring tailwater elevation data. The sensors can only provide information to the MCU's, and in the figure they are depicted with arrows into the interface cards to show the direction of information flow.

39. The bus into which these cards are plugged has a total of eight slots. Each interface card can accommodate the output of up to 10 sensors, making it possible to monitor the output of up to 80 sensors with one MCU. Any slot not presently in use can be used for future expansion for additional sensors.

40. The MCU's are connected to the NMS by both hard-wire connection as well as radio networking. The "WES1" MCU is hard-wired from the inspection gallery to the powerhouse, while the three MCU's in the embankment ("ME," "DK1," and "DK3") communicate with the NMS through the radio network. Since the MCU's can communicate data to the NMS, and the NMS can send instructions to the MCU's, they are both capable of sending signals as well as receiving them, and are represented by double-headed arrows in Figure 5.

Radio networking

41. Quite often the locations of sensors at a project are so widely dispersed that the lengths of cable needed to connect the sensors to the computer becomes very large. In other instances, the path which the cable must take can be destructive to the cable itself. In these cases, it becomes more economical to transmit the sensor data by an alternate means. Radio networking is one of these methods.

42. At Beaver Dam, the automation of the 84 piezometers in the embankment could have been accomplished by running cable from each of the piezometer tubes directly to MCU's located in the powerhouse. However, the lengths of cable which this would require, as well as the trenching of the embankment to protect the cable, would have been highly cost prohibitive. Instead, it was more economical to install the three MCU's at strategic locations on the embankments, run cable from the sensors to these MCU's, install radio transmission and receiving equipment in the MCU, and then send the gathered data to the MCU in the powerhouse via radio network.

43. Each of the three MCU's in the embankments received a two-way communications card which connects the MCU to a radio receiver/transmitter. The data collected by the embankment MCU's can be transmitted by VHF or UHF frequency. The MCU in the powerhouse is similarly outfitted for two-way communication via radio. This eliminated the necessity of running 84 cables very long distances at a very expensive cost.

Network monitoring system

44. The NMS is the overall center for providing information to and receiving information from the system and all its various components. All requests for data collection are initiated from this station, and all data that are received from an MCU or other controller are stored in and further distributed from the NMS. It consists of a central processor, volatile and nonvolatile memory, a data storage and retrieval system, monitor, keyboard, printer, and communications hardware. This unit contains the software which allows the user to control the MCU's, control the reading cycles of all the sensors, and act as the central traffic manager for communication with remote terminals and computers. A network monitoring station for a system can be any high level microcomputer having the above components.

Data communications

45. Local communications. The NMS can communicate with all of the

MCU's with personnel providing data input or instructions at a terminal, locally and remotely over telephone lines, as well as via satellite communications to computer systems having proper equipment to send and receive satellite signals. Input from system operators at the dam is accomplished through keyboard entry at the NMS, and output is received at the same station via display on the monitor or the system printer. At the NMS, data can be displayed, unscheduled readings initiated, reading schedules changed, and menu-driven interaction with the system to change the methods of collecting data. The system has a capability to accept input from and provide output to a portable computer via an RS-232 port at the NMS or any MCU. This allows NMS-like interaction with the system while the user is physically located near one of the MCU's.

46. Phone line communications. These same input and output capabilities are available to personnel at remote computers via phone lines using modems and communication packages which allow the computer to transmit and receive data as a terminal. At the site, a dedicated phone line has been assigned to the NMS which can be accessed at any time by District personnel for purposes of reading data. Those with the proper access codes can modify the software and set alarm limits via telephone communications.

Sensors

47. Pressure transducers for piezometer measurement. The 84 piezometer pipes which were automated by the US Army Engineer District, Little Rock, were not part of the demonstration project. Initially, they were the main purpose of installing the data acquisition and control system. The discussion of these transducers and the hardware used to accomplish this automation task, will serve to augment the discussion on instrumentation automation conducted under the REMR demonstration.

48. All of the piezometer pipes in the embankment and dikes are open tube piezometers. The method of automating these piezometers was to place a vibrating wire pressure transducer at the bottom of each of the tubes, and read the head of water pressure on the transducer. With the transducer at a known elevation above sea level, any sensed head of water can be added to this known elevation to produce the elevation of the water table in the system of piezometer pipes.

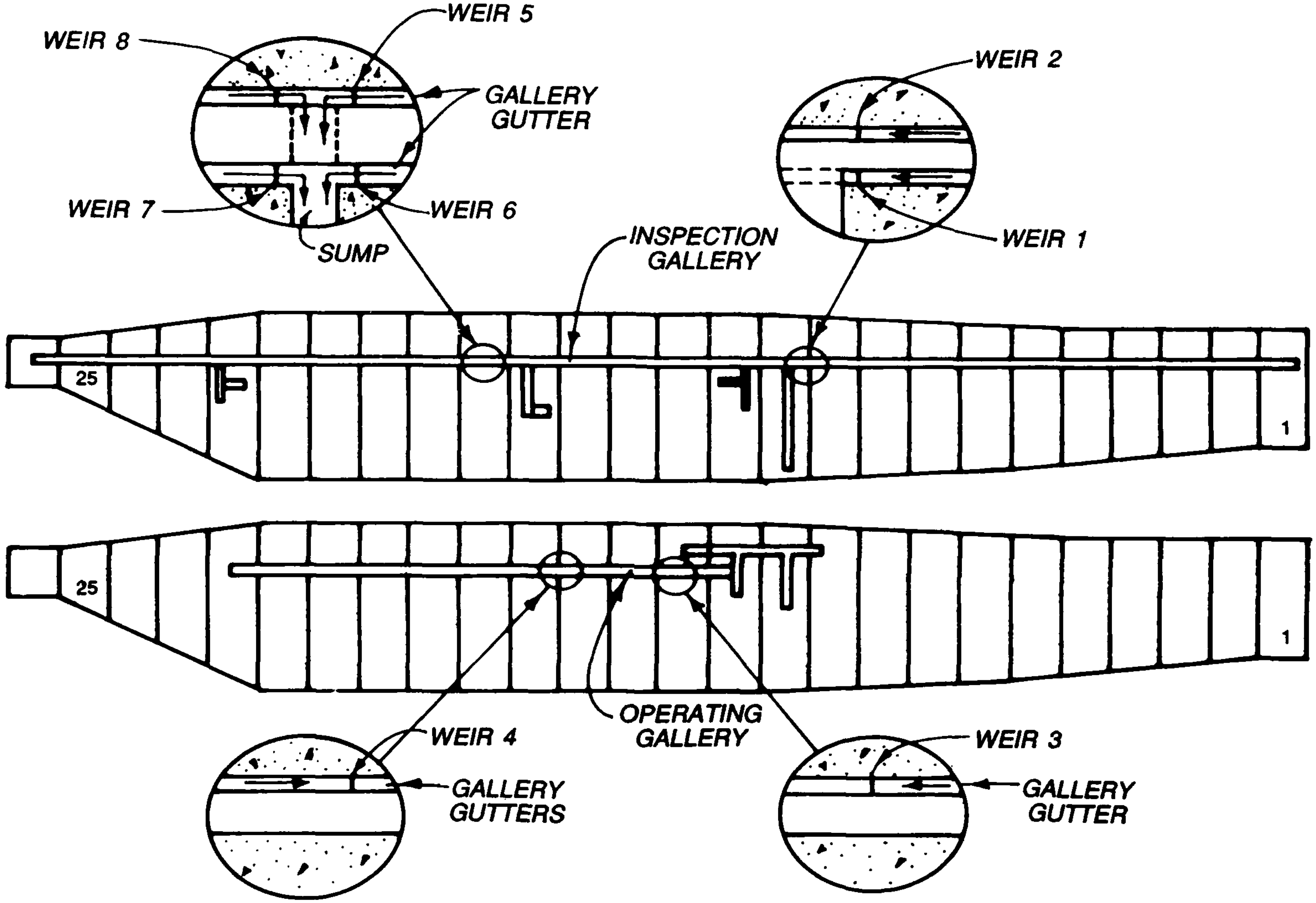
49. The vibrating wire pressure transducer works on the principle of vibration of a stretched wire. When a wire is electronically "plucked," it

vibrates. The frequency at which it vibrates will be related to the tension in the wire. The electronics inside the gage can both provide the wire with the electronic pluck and read the resulting frequency of the vibration caused by that pluck. If on one end the wire is connected to a diaphragm that is open to an outside pressure source, then pressure on that diaphragm will change the tension in the wire and consequently the frequency at which the wire will vibrate when plucked. The vibrating wire transducers are factory calibrated so that at sea level they have a given tension (and known frequency) in the wire at standard temperature and pressure. Under a head of water pressure, such as at the bottom of a water filled piezometer tube, the tension in the wire will be different than at calibration tension, and the wire will vibrate at a frequency reflecting the head of water above the sensor.

50. The frequency response of the sensor is calibrated for sea level, but the pressure head on the sensor is the combination of the head of water over the sensor and the site atmospheric pressure at the time of reading. Most vibrating wire pressure transducers eliminate the effects of site atmospheric pressure on the sensor by venting the back side of the sensor to the atmosphere. This is done by running a tube from the sensor along the electrical cable from the transducer to eliminate effects of the ambient atmospheric pressure. Since this installation of piezometer transducers was to be in a humid atmosphere, organic growth could form on the inside of the vent tube and eventually clog the tube. This would prevent atmospheric pressures from reaching the back side of the sensor and cause the reading to be inaccurate.

51. Instead of using transducers vented to the atmosphere, sealed transducers were used, and the reading that is returned reflects both water pressure and atmospheric pressure above the head of water. However, one sensor exposed only to atmospheric pressure was installed in the system, and it records site atmospheric pressure. These data were sent to the appropriate MCU's and were mathematically subtracted from the data obtained from the remaining transducers, thereby adjusting the output to read only water head above the sensor.

52. Submersible pressure transducers for weir flow measurement. There were eight locations in the gallery gutters where weirs were installed to facilitate the monitoring of leakage in the dam. Figure 6 shows their general location. Additionally, there was one weir on the main embankment of the dam.



NOTE: WEIR 9 IS AN EXTERIOR WEIR MONITORING EMBANKMENT DRAINAGE.

Figure 6. Location of weirs installed for the demonstration program

Water flow, whether from foundation drains, crack drains, or joints, occurs at several locations within the dam, and some water enters the gutters at most monoliths. It would be very expensive, in terms of sensors and weirs, to try to monitor the flow at every monolith joint to pinpoint sources of drastic change of flow conditions which could forewarn of structural changes in the dam. The nine weirs were strategically placed throughout the structure to monitor flow from groups of monoliths and from locations which traditionally had high flow conditions. With this setup, any drastic change in flow at a particular weir would identify the general location from which the increased flow was coming, and further monitoring could be done in that area to pinpoint the flow.

53. Weirs were placed in the gutters around the sump to record total flow into the sump. Two weirs were placed in the operating gallery in monoliths 12 and 13, respectively, and two weirs were placed in the inspection gallery in monolith 11 at the adit to the powerhouse to record flow coming from monoliths 1 through 11. One weir was placed in a sump at the foot of the embankment dam to monitor seepage and runoff occurring there. By monitoring the flow over these weirs, a continuing record of the flow associated with each group of monoliths can be determined.

54. The technique for reading the flow consists of installing the weir across the gutter, and placing a submersible pressure transducer upstream of the weir to read the pressure of the head of water that builds up behind the weir (Figure 7). As the flow over the weir increases or decreases, the height of water behind the weir will change appropriately, and the pressure transducer will sense this increase or decrease in head. This data can be converted into flow by the flow formula for the appropriate type of weir. There are two types of weirs which have been chosen for this task. When flow conditions will allow, a V-notch weir will be used; however, if flow becomes too extreme for the V-notch, a rectangular weir will be used. The drawing in Figure 8 gives the dimensions of both types of weirs.

55. The sensors that measure the head of water behind the weir are stainless steel, fully submersible pressure transducers with an operating range of pressures from 0 to 12 in. of water (0 to 0.43 psi). They have an accuracy of ±0.5 percent full scale, and provide a 4- to 20-mA output signal to the interface card in the MCU.

56. <u>Carlson joint meters.</u> Carlson joint meters were used to monitor

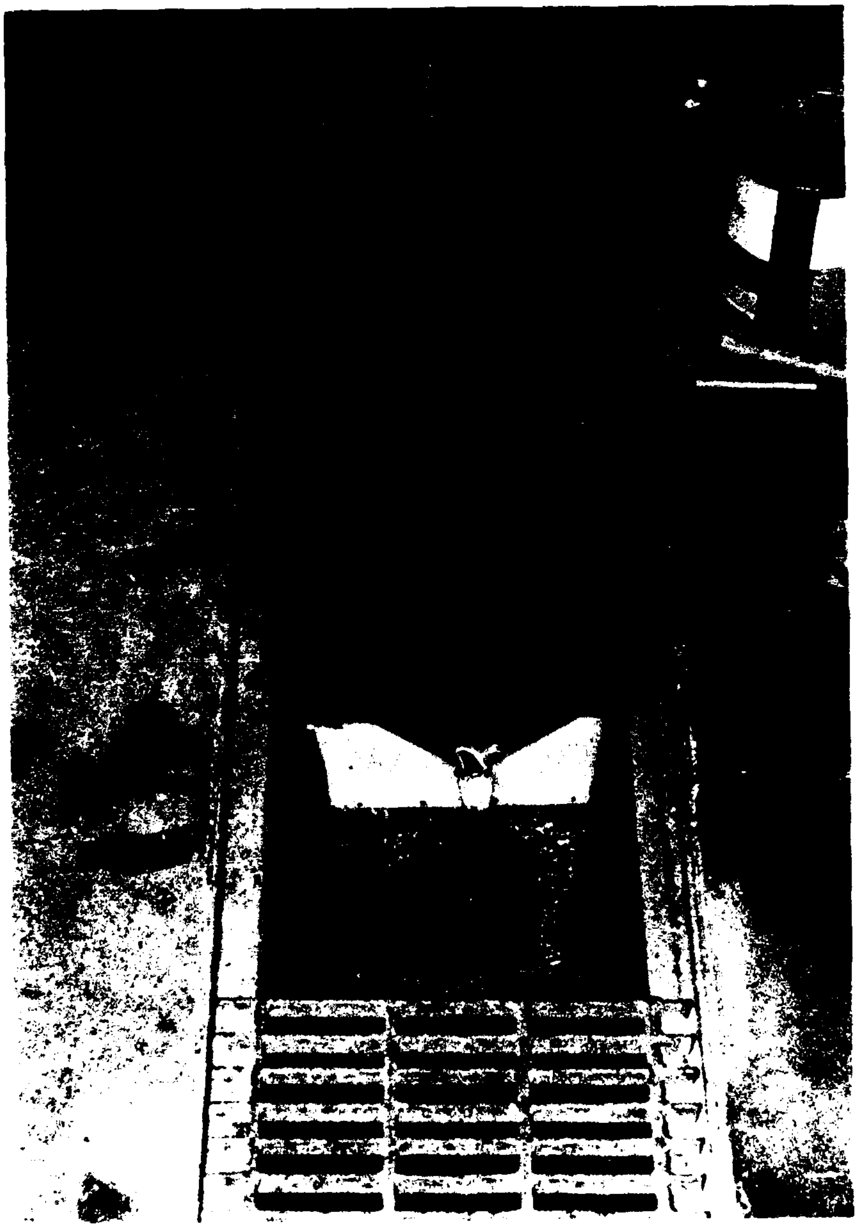


Figure 7. Installation of pressure transducer behind V-notch weir

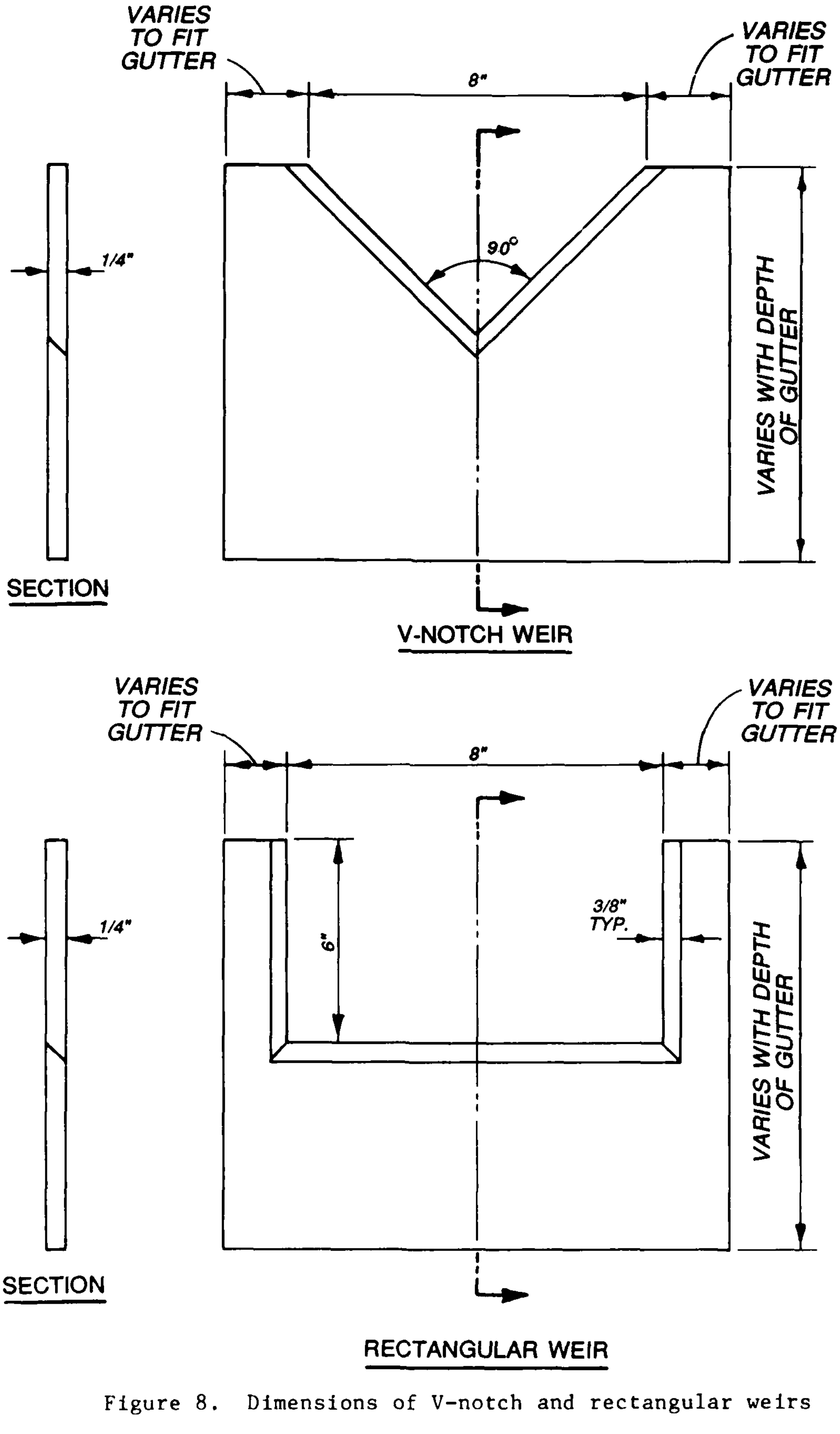
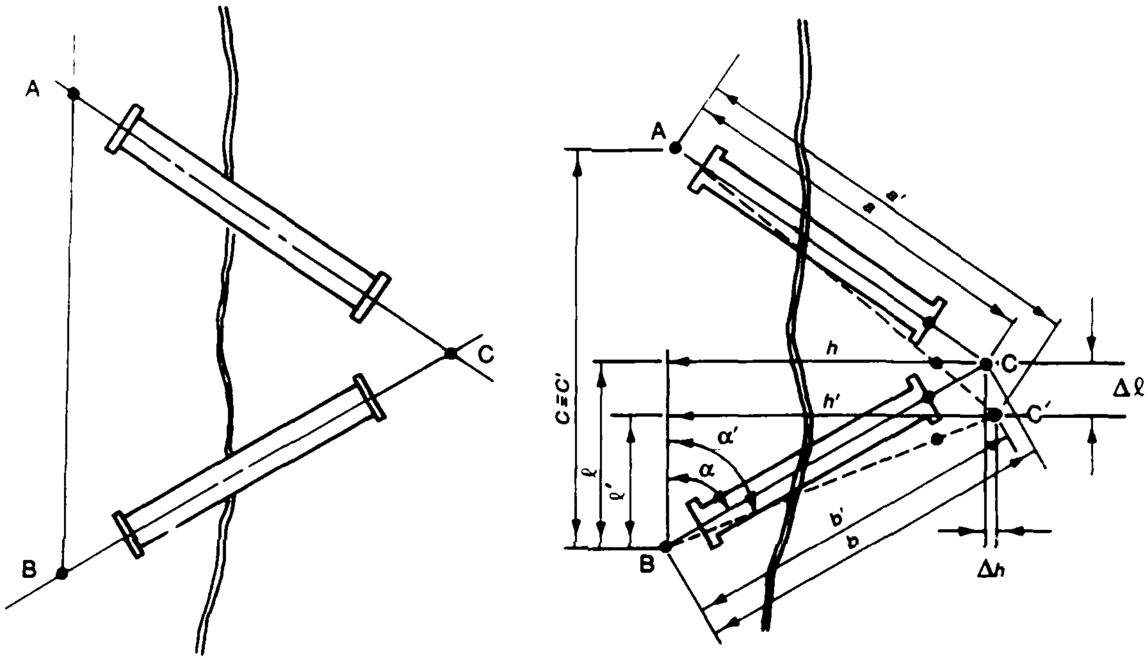


Figure 8. Dimensions of V-notch and rectangular weirs

the movement of several cracks in monoliths 16 and 23. These cracks were monitored for two reasons; one, to demonstrate the ability to automatically monitor cracking in concrete, and the other to demonstrate the capability of automating the family of Carlson strain instruments which are installed in so many concrete structures throughout the Corps.

57. The cracks were instrumented as shown in Figure 9. Two meters were placed across each crack in order to monitor movement in both the x and y



DISTANCES a, a' b, b', c AND c' ARE KNOWN

$$\cos \alpha = \frac{b^2 + c^2 - a^2}{2bc}$$

$$\ell = b \cos \alpha = \frac{b^2 + c^2 - a^2}{2c}$$

$$h = \sqrt{b^2 - \ell^2}$$

$$\Delta \ell = \ell - \ell' \qquad \Delta h = h - h'$$

TO OBTAIN COS α', h', AND ℓ' SUBSTITUTE PRIMED VALUES OF a, b, AND c ABOVE.

Figure 9. Schematic of crack instrumentation setup with equations to calculate crack movement

directions. The theory behind this technique uses the law of cosines and triangulation to determine the relative movement of the concrete on either side of the crack or joint. Knowing the lengths of the three sides of a triangle, the interior angles can be calculated, and through simple geometry changes, movement in x and y can be calculated. A schematic with the appropriate equations is also shown in Figure 9.

58. Scanning pressure valve. The automation of the uplift pressures on the foundation of the dam was accomplished by means of a scanning valve which utilizes one pressure transducer shared by up to 48 uplift pressure cells. The scanning pressure valve, shown in Figure 10, consists of 48 input water pressure ports, one pressure transducer, a rotary pressure selection mechanism, a solenoid drive, and electrical circuitry to receive input from and transmit output to the MCU.

59. The uplift pressure cells at Beaver Dam terminate at reading cutouts in the inspection gallery. They consist of 1-1/2-in. pipes capped by a 1-1/2-in. pipe cap in the reading cutout. The pipe cap is fitted with a 3/8-in. brass gage cock and an adapter to fit and Ashcroft Inspectors Test

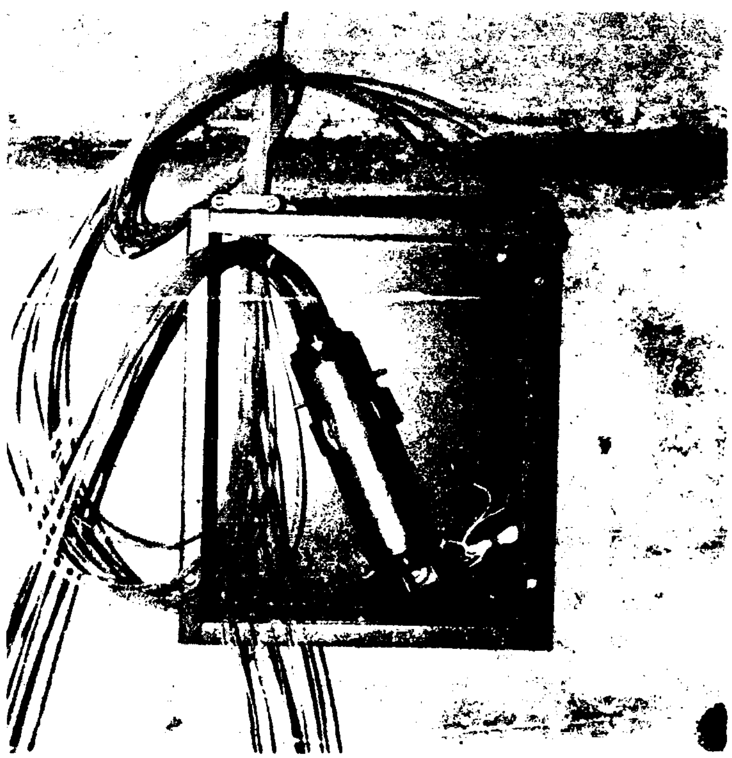


Figure 10. Scanning pressure valve with hydraulic pressure lines leading to the valve

Gage. To automate the reading of the water pressure, the water pressure from each uplift pipe had to be sent to the input ports of the scanning valve. This was accomplished by installing a T-pipe section into the threaded part for Ashcroft Inspection Test Gage. The base of the T-section was fitted with a male sleeve specially designed to accept the tubing to the scanning valve, while the remaining end of the T-section would be available for attachment of the inspectors test gage. The T-section allows water pressure to be ported to the scanning valve at the same time continuing to allow the water pressure to be manually read by the test gages. The special male sleeve consists of a 1/8-in. nipple which allows 0.062-in.-diam-high pressure tubing to be connected between the uplift pressure cell and the scanning pressure valve (Figure 11).

60. The scanning pressure valve takes input water pressure from the selected input port and delivers the pressure reading to the sensing element in the transducer. This is accomplished by means of the rotary pressure selection mechanism in the body of the scanning valve and the solenoid motor which drives the rotary mechanism. The pressure transducer, in turn, converts the individual pressures into 4- to 20-mA current output signals. The output signals are sent via a transmitter to the MCU along with a BCD signal which identifies the number of the port from which the measurement was made.

61. The MCU sends input signals to the scanning pressure valve to take readings from the uplift pressure cells. The valve can read all 48 ports, a selected range of ports, or individual ports and deliver the output back to the MCU.

62. Tailwater encoder. The lakestage and tailwater elevations at Beaver Dam are recorded using Leupold and Stevens recorders. These recorders have been automated by attaching an incremental rotary encoder, shown in Figure 12, to the exiting recorder. A second gear mechanism and rotary shaft is installed on the main rotary shaft of the Leupold and Stevens recorder. The encoder is then attached to this geared shaft, and any rotation of the main rotary shaft will be passed on to the second gear mechanism attached to the encoder. The encoder acts as a switch closure device. As the main rotary shaft of the Stevens recorder rotates, the drive gear that connects the encoder to the main shaft rotates, causing the switching mechanism in the encoder to send signals to the incremental encoder module in the MCU. The encoder has a resolution of 200 parts/revolution of the encoding shaft. This

Figure 11. Uplift pressure cell with reading gage removed and T-valve installed

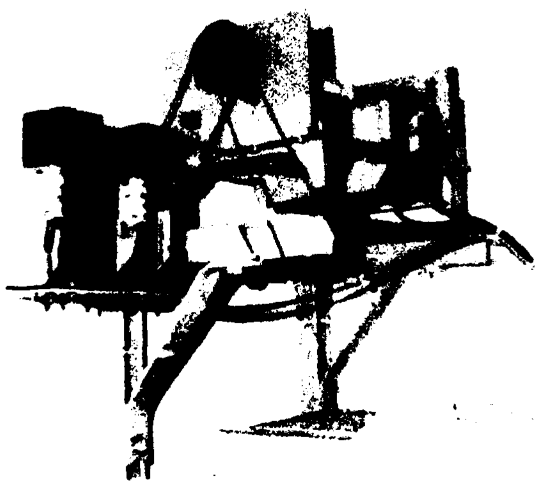


Figure 12. Two incremental digital encoders attached to Leupold and Stevens recorder at Beaver Dam

translates to a smallest reading of approximately 0.01 ft of change in elevation of the water level. The incremental encoding card can count up to 65,000 contact closures representing over 325 revolutions of the encoding shaft, or over 650 ft of elevation change. Since the encoder can also detect a change in direction of the shaft, it automatically knows whether the water level is rising or falling with each reading.

Measurement and Control Units

Central controller

63. The MCU's are the central collection point for data gathered from the sensors. At Beaver Dam there are five MCU's. A schematic of one MCU is shown in Figure 13. The schematic does not represent any one of the five MCU's at Beaver; but, for discussion sake, it brings together elements that are important to all of them. The basic control unit of the MCU is the central controller board. This unit contains the power management hardware, power status circuitry, alarm and shutdown circuits, and two I/O bus structures. One I/O bus is for communicating with the sensor via the sensor interface cards, and the other is for high-speed communications with system memory, keyboard and monitor display, and user I/O. Also within the MCU are the internal system battery, date and time clock circuitry, and a backup battery for the internal clock.

Power management

64. The MCU is powered by a 12-V DC power source. In areas where 120-V AC line current is available, the 12-V DC power source is charged by rectified and conditioned AC line power, thereby providing an uninterruptible power supply to the MCU. All of the circuitry for managing the DC power which is used to run the MCU is contained on the central controller board. Since power resources at sites such as locks and dams is sometimes unreliable, the system has the capability to manage the power to get the best use out of the power which is available, and to protect the data being collected in the best possible manner. The MCU's have three operating power modes under which the system can be run:

a. A continuous power mode where the MCU is on-line running from the 12-V DC power supply which is constantly backed up by the rectified line voltage. In this mode no operating restrictions are imposed on the MCU.

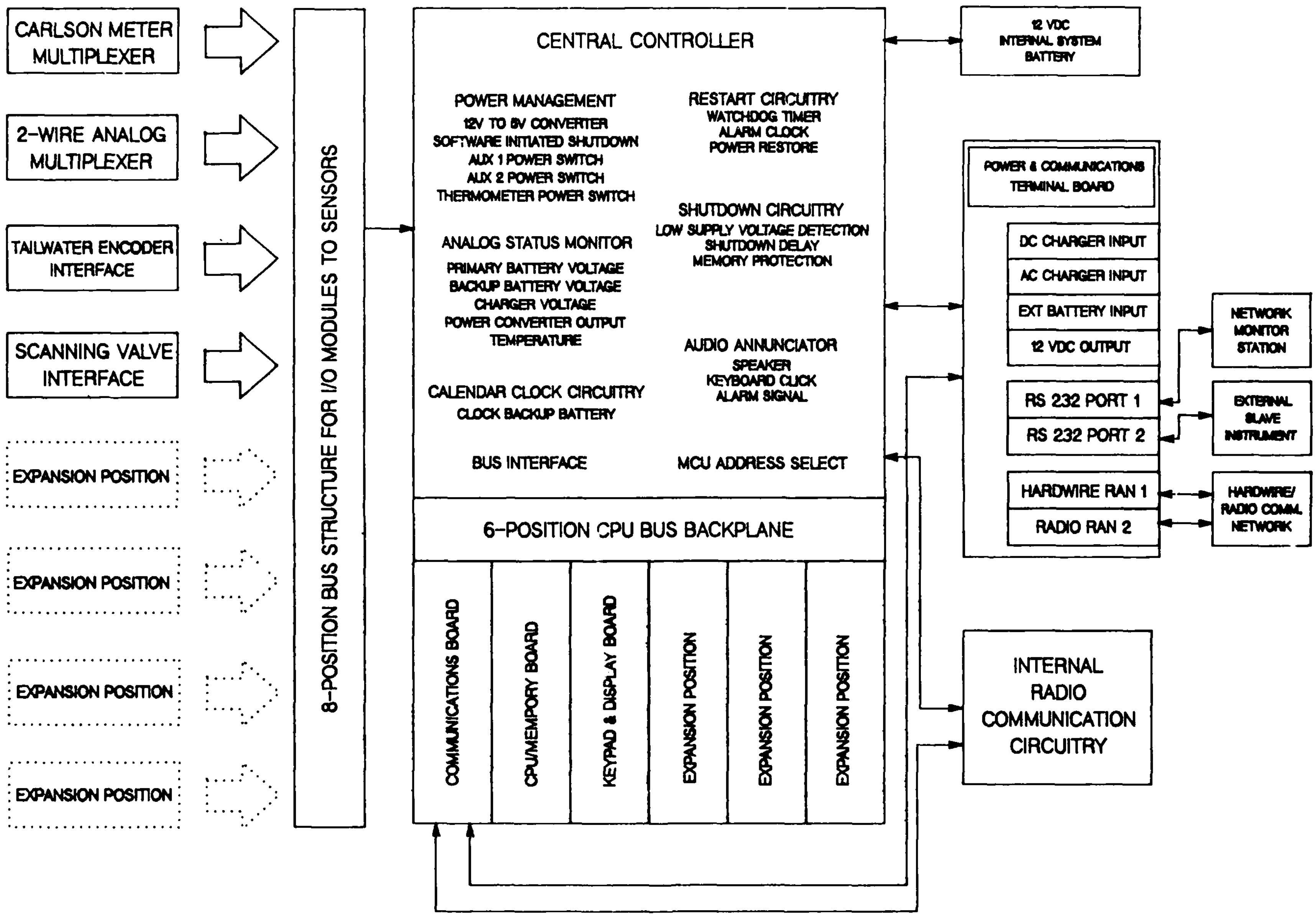


Figure 13. Schematic diagram of the measurement and control unit showing the component relationships

b. A low-power mode for solar recharged installations, where the duty cycle is restricted for radio transmissions and power-strobed sensor excitation.

c. An ultra-low power mode, generally initiated when backup power has failed, in which the system can shut itself down in between scheduled reading times and activate itself only to take the necessary measurements. In this mode, only MCU initiated communications are made, and reporting intervals are limited to a maximum of once every 8 hr. Under these conditions, system operation can last for 3 months without input of additional power.

Analog status monitor

65. The levels of the voltages which are used to run the MCU are monitored from the analog status monitor. This circuitry is designed to determine whether the supply power levels are within proper range, and what is to be done if power fails. Three conditions of MCU power are monitored:

a. The voltage of the primary battery supplying power to the MCU.

b. The voltage of the backup battery supply.

c. The security of the primary charging source connected to the battery.

These functions are monitored as one of the "system" status/diagnostic parameters, which are reported to the NMS as an alarm for an abnormal state or level.

Shutdown circuitry

66. Should the analog monitoring circuitry detect a primary battery supply drain below a critical level, the internal processor is interrupted from its normal chores, and a set of instructions are executed which prepare the system to be shut down in an orderly fashion. At that time measurements currently in volatile memory are saved to a special 24-K byte* section of memory which is protected by the backup battery supply. In addition, before the shutdown is put into effect, all the setup information is stored in the same memory location. This is done in order to have the proper instructions to reconfigure the system when power is restored. Once the critical system information has been stored, the system switches to the very low power backup battery operated mode. The backup battery is a lithium power source designed

* Throughout this report, when referring to computer memory, the symbol K refers to 1,024 bytes of memory, and M refers to 1,024,000 bytes. Therefore, 24K refers to 24,576 bytes, and 1.2M refers to 1,228,800 bytes.

to maintain its power for a long shelf life and to have a useful service life of about 3 months. Sufficient battery power is used in this mode to keep the special section of memory properly powered, and to periodically check the voltage level of the primary battery to determine if and when conditions are again satisfactory. When this occurs, the shutdown circuitry initiates a restart.

Restart circuitry

67. A reset of the MCU, because of primary power disturbance or watchdog timer reset, is designed to accomplish a complete recovery of the system with all setup parameters intact. This reset will occur when the shutdown circuitry determines that power has been restored to the MCU. During a restart, the MCU checks the battery operated calendar/clock circuitry, and reinstalls the correct date, and time-of-day scheduled. The system setup data that was saved prior to shutdown is reinstated, and running data averages, which were being collected at the time of any shutdown, are recalled and identified as data collected before the shutdown.

Audio annunciator circuitry

68. The audio annunciator circuitry controls some of the background features of the MCU. The alarms which are triggered by the MCU software are announced via a speaker on this board. This speaker also produces an audible click in response to the pressing of a key on the keypad to reinforce the fact that the key has been properly pressed and the data entered. This click sound is capable of being turned off if the software is toggled to mute the noise.

Bus interfaces

69. As previously described, there are two interface busses which allow communication between other devices and the main central controller of the MCU: an eight-position sensor interface bus that accepts the sensor interface boards, and a six-position backplane bus which allows communications with peripheral devices, memory, and users.

Six-position backplane bus

70. As configured in the Beaver Dam system, the six-position backplane bus contains a communications board, a CPU/memory board, and a keypad/display board.

Communications features

71. The communications board contains all the circuitry to allow the MCU to communicate with the NMS, any external control device, and any external

communications network. There are four asynchronous serial ports on this board. Two of the ports are available for hardwire or radio communications capabilities through two on-card modems. They are referred to as remote area networks (RAN's), RAN's 1 and 2, in Figure 13. The other two ports are configured to meet the standards of Electronics Institute of America EIA RS-232-C specifications for serial communications. These two ports can be used to connect outside instrumentation data with the MCU, allowing that data to be used by the MCU just as if it were collected from the sensor interface bus. One of these ports is used to connect the NMS to the MCU, and all four of the communications ports can be used for MCU interaction.

72. One of the advanced features of this setup is the ability of the MCU's, as well as other network components, to communicate among themselves (network) through these asynchronous ports. This allows multiple forms and routes of communication to be supported by the system and allows data to be accessible anywhere from any one of the MCU's. Secondly, any MCU can intercept or retransmit any message sent on the system. This allows each MCU to act as a repeater in the event that data or messages must be sent via hardwire over long distances. Several of these conditions are depicted in Figure 14 which shows a schematic drawing, similar to Figure 5, of the NMS and the MCU's. Three forms of the network topology are depicted here. The powerhouse MCU acts as a central collector of data in the system. The three embankment MCU's communicate with the powerhouse MCU via the radio network (RAN 2) because they are so remotely removed from the powerhouse. Each of the embankment MCU's has a radio transmitter/receiver, and can communicate directly with the powerhouse MCU; however, each could have been configured so that only one had a radio with the other two hardwired to the radio-equipped MCU via RAN 1. The dam MCU is wired to the powerhouse unit via a hardwire configuration (RAN 1). This type of network connection is a twisted wire pair, half duplex communication protocol which allows multiple units to be connected and restricts communication to one direction at a time. The powerhouse MCU communicates with the NMS via the EIA RS-232-C network. This is the standard method of computer-to-computer communication.

73. The RAN protocol has special features to prevent loss of data when two units are attempting to transmit at the same time. In general, these units attempt to transmit only when there is silence (lack of carrier) on the line. However, since radio compatibility requires approximately 30 msec to

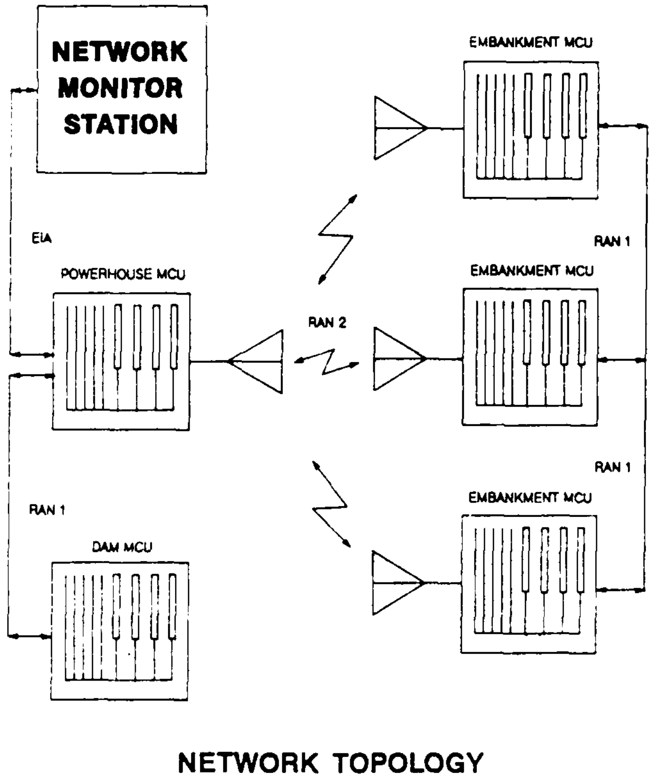


Figure 14. Schematic drawing of the various network schemes used at Beaver Dam

detect a carrier, the two units may be trying to send signals to each other during this short 30-msec period, and there will be a collision of the data with some data being lost. The collision avoidance feature utilized by the RAN ignores data transmitted without the proper acknowledgment signal (lost in the collision), and the original unit will retransmit the frame after waiting a random amount of time. The random period is necessary to minimize the possibility of the units again transmitting at the same time.

Central processing unit memory board

74. The central processing unit (CPU) for the MCU is a 16-bit microprocessor that is compatible with the MS-DOS operating system. It resides on the CPU/memory board along with the random access memory (RAM) for the MCU. The system has 256K of RAM. The majority of this memory is used for running the software which controls the MCU's and reduces and reports the data to the NMS; however, 24K of this memory is partitioned to store data taken from the sensors and to hold the current setup information.

Keypad and display board

75. The MCU's have an option which allows installation of a keypad and a 24-line by 80-character-per-line display. This option is designed to allow the user to interact with the system while at the MCU without having to return to the location of the NMS or having to carry a portable input unit such as the portable network monitor. This keypad allows the same input and interaction capability with the MCU as does the NMS. The user can modify reading schedules, change alarm limits, cause the MCU to read all or only some of the sensors, and pass messages to other MCU's or the NMS.

Expansion space

76. There are three open slots on each of the six-position backplane busses. These are available for expansion of memory, communications, or other special duty cards which the system may need in the future.

Eight-position
sensor interface bus

77. This bus provides the interface between the instruments and the MCU central controller (see Figure 13). Each MCU is capable of accepting eight cards on this bus. There are a number of different interface cards designed for this purpose. The following paragraphs describe the various cards which are installed in the different MCU's in the Beaver Dam demonstration.

Piezometer interface card
and vibrating wire converter

78. The vibrating wire piezometer uses a four-conductor cable. Two of the wires in this cable are connected to an electromagnetic coil in the transducer. These wires carry the excitation voltage which plucks the vibrating wire and return the current which identifies the frequency at which the wire is vibrating. The other two wires are provided as a thermocouple pair for temperature measurement. The interface card is a two-wire multiplexer module. It has the capability of interfacing up to 10 two-wire sensors into the MCU. The card is a very useful interface, in that a multitude of different sensor types can be interfaced to the MCU using this card. Each channel can be individually configured to read output voltage, current, resistance, or internally excited current loops. Additionally, there is a 28-V DC power source on the card which can provide any 4- to 20-mA current transmitters the proper source voltage.

79. This type of interfacing card is valuable in a data acquisition

system because it allows one interface board to do many tasks. In large installations such as Beaver Dam, where there are 84 similar transducers to monitor, several of these cards can be used to monitor the same measurement type. However, in a situation where three voltages, two resistances, and five current readings are all that must be monitored, a multifunction card as this eliminates the need to purchase three separate interface cards to do the job.

80. The two-wire multiplexer board is assisted in the chore of reading the output of the vibrating wire transducers by a vibrating wire excitation and measurement module. This circuitry provides the excitation voltage to the electromagnetic coil of the sensor, and a frequency counter in the module determines the returned frequency of the vibrating time.

81. Carlson meter multiplexer. The Carlson meter card interfaces three-wire (one resistive element) and four-wire (two resistive elements) type Carlson meters, and provides lead-wire resistance compensation for the meters attached to the card. Each card can accommodate up to five Carlson type meters. For this demonstration, one card was purchased and four Carlson joint meters have been automated.

82. The Carlson family of meters are resistance devices which are normally connected to a wheatstone bridge reading circuit when read manually. This method of reading the gages is possible when using an automated monitoring system, but it is difficult to accomplish or very expensive.

83. Regardless of the reading method, inaccuracies can occur in two areas. Lead wires from the Carlson meters, which can often be of unknown length when trying to automate previously installed meters, are difficult to compensate for, and the resistance measured due to these unknown lengths of wire often remains inaccurate. Also, to conserve expense of reading circuitry and to make readings on both resistive elements within the Carlson gage, switching techniques are often used. The resistance due to switch contact closure is a measurement error, and is not repeatable from one closure to the next. Elimination of this error requires the extreme expense of attaching reading circuitry for each element in each Carlson meter.

84. Many automation schemes for reading Carlson meters use a technique of reading the resistance due to the unknown wire. This technique can find the true resistance in one of the elements of the Carlson meter and can adjust the other resistance to factor out the lead resistance. It can be used on any

Carlson meter which has four leads coming from the gage. It is particularly useful when the length of the lead wire is not known.

85. Figure 15 shows a typical four-wire Carlson meter circuit connected to a data acquisition system. The current source in the data acquisition equipment provides voltage with constant current around circuits A through I, inclusively. This means that unknown lengths of lead wires CD and FG contain a constant current which produces resistances r1 and r2 in these leads. However, lead wires DJ and EK are not part of the constant current circuit and, therefore, have no current running through their lengths. When the digital voltmeter is connected across JK, as shown in Figure 15, the voltage drop recorded is due only to the resistance of the Carlson element R1. When the voltage drop across element R2 is to be recorded, one of its lead wires, FG, contains current and the resistance, r2, will be part of the total voltage drop recorded. This resistance is not known due to the unknown wire length, and cannot be directly eliminated. However, the digital voltmeter can be switched to read the voltage drop across terminals CJ, which records only the voltage drop r1, due to the resistance of the unknown wire length DC.

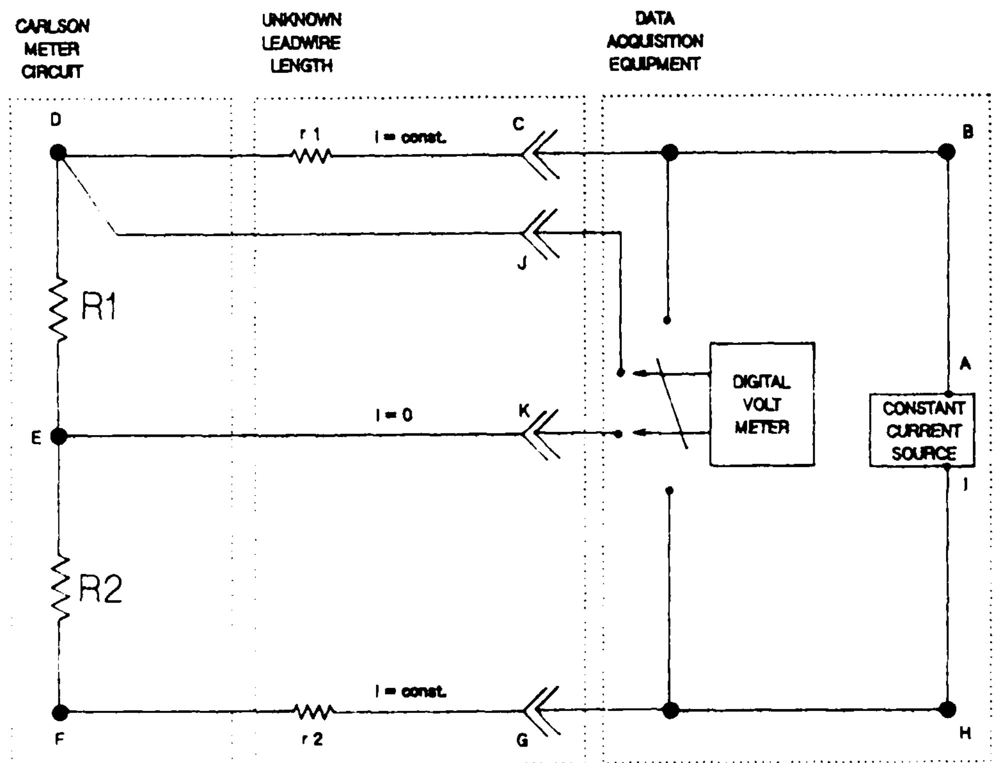


Figure 15. Carlson meter four-wire measurement circuit

This can assumed to be the same as r2 and can be mathematically eliminated from the voltage drop across R2. This procedure completely isolates the resistance due only to the measuring elements in the Carlson gages.

86. Lakestage and tailwater encoding card. The incremental encoding module in the MCU receives its signal from the encoder attached to the main shaft of the water level recorder. The signals returned are low-power electronic pulses which are stored on the encoding card, and updated when the encoder has detected a change in water level. Each time the encoder rotates 1.8 deg, the equivalent of 0.01 ft of change in water level, the encoder transmits a pulse to the encoding card. The pulse is added or subtracted to the information being stored on the encoding card, and the latest water level calculated. This measurement process is conducted on a continuous basis regardless of the frequency of an MCU interrogation by the NMS. When the NMS does request a reading, the encoding card has the latest water level elevation to pass to the central controller. Since this is a continuous process, and the information that is passed to the encoding card is a relative increment, the encoding card must always have the last increment to add to the present increment. This means that the information on the encoding card must be battery backed not to be lost in case of a power failure. In fact, the card is run from line power and backed up by an on-card battery. Should power fail at the MCU, the encoder will continue to send pulses to the encoding card, and the battery power will continue to maintain the relative measurement current so that when power is restored, the water elevation stored in the encoding card will be correct.

87. Scanning pressure valve interface. The scanning pressure valve scans the water pressure input ports in response to direction from a solenoid controller module applied with the valve. This controller issues commands to the valve to "step" from one input port to the next, or move to the "home" port of the rotary valve. Two interface cards in the MCU are needed to automate this task. The first is a relay output module, and the second, a pulse input module. Two relay channels on the relay output module are connected to the "step" and the "home" circuitry in the scanning valve solenoid controller. As commands to "step" or "home" are issued by the MCU, the relays pass them on to the solenoid controller. The MCU, in turn, interprets the BCD signal being returned from the scanning valve to identify the port which is presently the active port. This information is used by the MCU to pass on additional

commands to the scanning valve, such as which port is to be selected as active port and when to move to the "home" port. With the number of the active port known, the interface card can accept the pressure information from the scanning valve.

Network monitor system

88. NMS responsibilities. In the hierarchy of the system, the NMS is considered a support element responsible for monitoring all functions of the data acquisition units attached to it and providing a means of user interaction with, and modification of, all system components. It provides reports of data collected from the MCU's and takes care of housekeeping chores associated with the operation of the overall system.

89. The NMS has been designed to eliminate the need for an operator to have any specialized skills of a computer programmer. It is anticipated that the NMS will be used by operations and maintenance personnel who are not necessarily skilled in the operation, use, or programming or general-purpose computer systems. With this in mind, the software which controls the operations of the NMS is accessed and utilized by keyboard selection of appropriately annotated, system-generated, prompts and menu choices. The NMS has been designed to provide the following functions:

a. To act as a workstation for creating and managing MCU configurations and network topology to include setup, downloading to the MCU's, and providing data printout.

b. To provide a real-time data display to show user specified measurement and control points, configurable display pages, and alarm displays.

c. To annunciate alarms in various forms according to user specification (screen display, printout, alarm relays, and optionally dial-out voice reporting).

d. To act as a supervisory control station; to issue operator dispatched commands to the MCU's on the network and modify MCU setup and configuration files.

e. To be used as a data logging station to log measurements, alarms, and MCU status parameters on user-specified schedules.

f. To act as a file management system to store, transfer, and archive MCU setup configurations and data history files.

g. To provide remote terminal operation of the NMS from a distant location over the public telephone network and to transfer data, configuration files, and messages from the MCU's and NMS to remote computer systems.

Hardware Capabilities/Components

90. The amount of system control equipment which is necessary for any automation project will be a function of the measurement job being performed. The controlling computer hardware at Beaver Dam was chosen to fit the requirements of the automation task. For instance, one of the alarm reporting requirements was a capability to annotate the cathode-ray tube (CRT) screen of the NMS with different colors to represent the status of an alarm. This required the use of a color monitor. If the application did not require the use of color display, money could be saved by using a monochromatic display. The components of the NMS hardware are listed and described in paragraphs 91 through 93.

- a. A 16-bit CPU with the MS-DOS operating system
- b. A system real-time clock/calendar
- c. 640K bytes of RAM
- d. Two double-sided, double-density, 5-1/4-in. internal, floppy disk drives, each with 1.2M bytes of storage capacity
- e. One 20-M-byte internal hard disk drive
- f. One color monitor and video interface
- g. One color printer with tractor feed
- h. A 1,200-baud modem

91. CPU. A 16-bit CPU was specified to take advantage of the memory addressing capabilities. The smaller 8-bit CPU's do not allow enough memory addressing capabilities to accommodate the programs necessary to run the NMS and the MCU's. The operating system was chosen for the wide range of data reduction and presentation software available using that system.

92. Clock/calendar. The clock/calendar is a necessity in an environment where power outages or system resets happen frequently. Without a battery backed-up clock/calendar, an unattended system will not report the proper time when the system restarts nor will it collect data on the proper time cycle.

93. Auto-restart capabilities. All system power switches have been designed to remain in the same orientation when power is removed from the system. This will allow restart under the same conditions when the power is again returned. As with most microcomputer systems, the NMS uses an autostart program which runs automatically when power is applied to the system.

This allows the system to read data which was saved prior to power shutdown and restart the system with this data intact. The log-on procedure also queries the time/date hardware and produces a hard copy of the time and date on the system printer when the system regains power. This tells the user how long the system was not working.

94. System storage capacity. The 20-M-byte hard disk drive was chosen to allow the NMS to automatically load a variety of large programs without the need to have a user insert a diskette containing the software for these programs. This size storage capacity leaves an ample amount of disk space for the storage of collected data over a long period of time, again without need for user interaction. The NMS software archives all data collected in a given period and stores it in automatically created data files on this hard drive.

95. Color output devices. The necessity for the color printer and monitor is associated with the sophistication of the alarm system software. The use of flashing colors on the monitor and the use of colors to identify hard copy output makes these items necessary and an aid to quickly identifying potential problem areas.

96. Modem. The modem is necessary to allow remote communication with the NMS from Corps district or division offices. The modem was chosen to have communications at rates up to 1,200 baud, allowing rapid transmission of data if line conditions are good, and slower rates if transmission at the higher rates produces garbled data. The modem, and software to run it, has the capability to send information out automatically as well as automatically accept transmissions from a remote terminal at any time.

Software Capabilities

Ease of use

97. The usefulness of any data collection system is, in part, a function of how easy it is to use. If it is simple and straight forward, it will be used more often. The operator will understand it better, and utilize it more to its fullest. The most common way in which an individual interacts with a data acquisition system is through its software. If this part of the system is well designed, it will make using the system a much smaller chore.

98. Just what should be expected from the interactive software of a data acquisition system depends on the size and complexity of the system

itself. A simple system, which collects only one kind of information from a small number of sensors, can be effective with a simple computer/keyboard and a line printer as the only means of interactively communicating with the software. This is mainly because there are not a lot of things which need attention. If the tasks are simple, there will usually exist commercially written data acquisition software packages to control the hardware. These packages generally will give the user display of the data and some data reduction capabilities. They have been written in a general manner to appeal to a broad range of customers. Several of these packages have been described by Currier and Fenn.* However, as a system becomes large, the needs become sophisticated, and perhaps controlling many different types of instruments, the software must be custom designed to fit all the specialized needs. In these larger systems where many variables need to be changed on a frequent basis, the usefulness of the system breaks down if the interactive system software is not easy to use.

99. A well-designed system control software package with the proper user capabilities should:

a. Be menu driven through all layers of the program.

b. Allow random and sequential access to all program levels.

c. Provide a clear description of present system readings and settings.

d. Show user what modification options are available.

e. Provide a summary of the modifications which have been made.

f. Provide for insertion and deletion of data channels.

g. Allow for electronic calibration of sensors.

h. Provide for conversion of sensor output to engineering units.

i. Provide output in a form compatible with other software.

j. Explain errors.

k. Provide a means of recovery from an error.

l. Provide for future expansion needs of the system.

All of these qualities improve the software useability and, therefore, its effectiveness in controlling the system hardware.

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* Op. cit.

Menus

100. The data acquisition system at Beaver Dam falls into the category of a large and diverse system. There are many different types of sensors and many different conditions under which they must be monitored. As a result, the software was custom designed for the data acquisition system chosen to collect the data. It was written so that all basic control is attained through screens of menus which the user chooses via numeric input. This software has eight basic levels of menus that program the system, modify system control, display output, or communicate with the system. Figure 16 shows menu 1, the main menu. It provides direct access to the eight menus which interact with the rest of the system. These menus are: Station Options Menu, Alarm Annunciator Panel Menu, Data Display Menu, MCU Configuration Menu, MCU Status Menu, Network Topology Menu, Issue Orders and View Traffic Menu, and Satellite Transmitter Menu.

101. <u>Menu access and means of modification.</u> All commands to the system are entered by a keyboard at the NMS, an MCU configured with a keypad and display screen, a portable keyboard and screen which attaches to any of the MCU's, or remotely from any computer or terminal which has the appropriate communication software to interact with the system. Input information can be

Menu input location

Level: 1 MAIN - Top Menu

Menu number

Menu control word

> 1 STATION - Station Options

> 2 ALARM - Alarm Annunciator Panel

> 3 DISP - Data Display Menus

> 4 CONFIG - MCU Configuration Menus

> 5 STATUS - MCU Status Menus

> 6 TOPOLOGY - Network Topology

> 7 COMMAND - Issue Orders and View Traffic

> 8 GOES - Satellite Transmitter

Figure 16. Main menu in the data acquisition software

displayed on any one of the screens by keying it in from the keyboard or keypads and executing the command by pressing a function key on the keyboard. All menus are accessed by number or by use of control words as shown in Figure 16. The main menu provides access to additional menu choices. If any menu has a submenu, a screen with the choices of submenu items will be displayed when the menu number is entered and executed. These numeric choices are composed of the present menu number followed by a decimal point and a number describing the further submenu. For example, menu 4 has seven submenus; the first is called 4.10, the second 4.20, etc. Menu 4.10 itself has 14 submenus. They are 4.11 through 4.24. These two submenus are shown in Figures 17 and 18. Access to any level menu can be sequential by stepping down (or up) through each of its neighboring menus or obtained directly by typing the correct menu number or control word from any screen. This method provides access to any level of the system very rapidly.

102. Once into the chosen menu, data can be viewed or acquired, or setups can be modified by changing the current setting values. The representation of two screens are shown in Figures 19 and 20 to demonstrate this capability. Figure 19 is a data display screen. This type of screen can be modified only by changing the menu level (shown in the upper left part of Figure 19, displaying "Level: 3.1") or the particular page of data being displayed (in the upper right displaying "Page: 1"). This is done by placing

Level: 4 CONFIG - MCU Configuration Menus

> 4.10 INPUT - Sensor Measurements

> 4.30 COMPUTE - Unit Conversion Computations

> 4.50 ALRM - Alarm Configuration Setup

> 4.60 OUTPUT - MCU Outputs and Control Functions

> 4.80 LOAD - MCU Configuration Control

> 4.90 ADM - Autodial Telephone Modem

> 4.99 WHAT - Generic MCU Configuration Menu

Figure 17. Submenu 4 of the main menu--MCU configuration menu

Level: INPUT INPUT - Sensor Measurement

>	4.11	VDC	- DC Voltage
>	4.12	OHM	- DC Resistance
>	4.13	IDC	- DC Current
>	4.14	VWC	- Vibrating Wire
>	4.15	CMSS	- Carlson Meter (Strain Type)
>	4.16	CMTT	- Carlson Meter (Temperature)
>	4.17	IEI	- Incremental Encoder Input
>	4.18	PIC	- Pulse Input Counter
>	4.19	PMS	- Pneumatic Multiplexer System
>	4.20	DIN	- Digital Input Bit/Byte/Word
>	4.21	TIM	- Time Interval Measurement
>	4.22	SVAL	- Scanivalve Multiport Pressure
>	4.23	PLM	- Plumbline Monitor
>	4.24	TC	- Thermocouple Measurement

Figure 18. Submenu 4.1 of the MCU configuration menu--sensor measurement

the screen cursor over the number behind level or page and typing the number of the corresponding menu level or data page you wish to display. The display in this figure is showing data collected from rain gages, barometric pressure sensors, lake stage gages, and weirs at Beaver Dam. The information given, from left to right, starting on the first line beginning with PP is: the MCU identifier, the I/O card number and the channel number for the particular sensor being logged, the date and time the measurement was made, the data, its units, and the identifier. Each line of data represents a measurement from one of the sensors.

```
Level: 3.1      DATA  - Programmable Data Display                    Page: 1

MCUN:CD.CH.SUFF DD-MON-YR HH:MM:SS      DATA      UNIT      LABEL/MESSAGE
PP  :01.01. MXB1 08-Jan-88 10:30:44     987.736 mBar
PP  :01.01. MXB2 08-Jan-88 04:03:23     0.716967 ftwt atmos pressure deviation
PP  :01.01. MXB3 08-Jan-88 10:30:44     29.1599 inHg barometric pressure
    :00.00.
    :00.00.
PP  :10.01. PIC  07-Jan-88 07:52:16           5 tips Rain gage bucket tips
PP  :10.01. MXB  08-Jan-88 00:00:01        1.25 inches of rainfall
    :00.00.
    :00.00.
    :00.00.
PP  :21.01. IEI  08-Jan-88 16:01:01      1119.95 feet Lake elevation
WES1:01.01.AXBC  08-Jan-88 16:01:01      1.38528 gpm Weir 1
WES1:01.02.AXBC 08-Jan-88 16:01:05       1.43674 gpm Weir 2
WES1:01.03.AXBC 08-Jan-88 16:01:07       0.96773 gpm Weir 3
F3/F4 ALL ON THIS PAGE

F1=EXEC  F2=MAIN  F3=FORCE  F4=RELOG F5=ENTRY F6=     F7=HELP  F8=EXIT
```

Figure 19. Representation of a typical data output screen

```
Level:  IDC        IDC     -  DC Current                    GNA:WES1:01.01.IDC


Range: [ AUTORANGING ]                        Execution:  [ Internal 28V ]
Integration time: [ 50 ms ]                   Sensor warmup:  [ .5s ]


Logging format:                               Evaluations: [ ENABLED ]
Units: mA                                     Logging class: [ NORMAL ]
Label: weir 1, SE corner sump                 Logging priority: [ EXPANDABLE ]
Evaluations start:  03-Aug-87 16:03:59        Logging start: 03-Aug-87 16:03:59
Evaluations interval:  12 [ HOURS ]           Logging interval:    0 [ SECONDS ]
Depends on WES1:00.00.IDC                     Logging destination: NMS


F1=EXEC  F2=MAIN  F3=DLOAD  F4=      F5=ULOAD F6=DEL    F7=HELP  F8=EXIT
```

Figure 20. Typical screen used to format a particular data collection channel

103. Figure 20 shows a typical submenu screen that is designed to let the user modify the configuration of the MCU for collecting a particular channel of data. As with the previous type of screen, the menu level can be modified, and on this type of screen, the page entry has been replaced with a channel identifier. All the settings on this type of screen can be changed by the user. Those settings which can be only a limited set of values are enclosed in brackets (such as the range value [AUTORANGING]). These entries are changed by moving the cursor over the setting to be changed and hitting the space bar. The range of allowable alternatives will appear, one by one, inside the brackets. In this instance the various ranges include: Autoranging, +/-.1V, +/-, +/-10V. Those settings which are not bracketed are changed by moving the cursor over the appropriate setting and typing in the setting desired. For instance, the logging interval gives an unbracketed number followed by the bracketed alternative, SECONDS. The unbracketed number could be changed to any number desired by the user, while the space bar would shift through the valid, bracketed intervals accompanying the number, SECONDS, MIN, HOURS, DAYS, WEEKS, and MONTHS. The logging start time could be changed to a date and hour 1 week from now, 2 months hence, etc.

104. All changes are put into action by hitting function key F1 (bottom left corner of the figure) which loads this screen of information into memory in the proper MCU and changes the data base as required.

105. The following paragraphs will describe the seven screens to demonstrate the ease of use and utility which any data acquisition software should have.

106. <u>Station option menu.</u> The station options screen allows one to decide what amount of data will be directed where in the system. The system has four classes of data logging: summary, a short synopsis of the data output; normal, the main details of the logged information; detailed, the maximum amount of information the system collects; and diagnostics, information about system health. Any and all of this information can be sent to the printer, the CRT screen, or to a logging or history disk file. This screen allows the user to tell the system how much of the information should be sent to which output device. Toggle options of yes or no are available for all four classes of logging to all four output destinations.

107. The above menu is quite necessary to prevent the system from saving all information generated, and rapidly filling up all remote storage capacity.

information to the CRT is obviously lost when the screen is replaced by another screen. Sending all information to the printer generates massive amounts of paper. Much of the information available does not change from day to day, and printing all of this information would be a waste of paper. Likewise, sending all information to disk will soon fill the disks and require purchase of another remote storage device. Prudently selecting what information gets saved will conserve disk space and save paper. This menu controls that function.

108. Alarm annunciator panel menu. This menu is similar to Figure 19, in that the data cannot be modified. It shows all channels of data which have exceeded the range of acceptable values set for them in the alarm range menu. The information given for each channel in alarm is similar to that given in Figure 19: the MCU identifier, the I/O card number and the channel number for the particular sensor in alarm, the date and time the alarm occurred, the data, its units, and the alarm message. The message given when a channel is in alarm is any message the user has previously programmed into the software. It can be something which tells about the alarm, or any other alpha or numeric information which may be useful to the user. An arbitrary number of alarms, set in engineering units, are permitted for each channel. Also, each alarm condition allows specification of whether an acknowledgment is required and whether or not an automatic voice report is to be executed.

109. This display also makes use of color and sound to provide information about alarms. If the channel in alarm requires user acknowledgement, an audible alarm will sound, and the channel on the display will flash red until a user acknowledges the alarm. User acknowledgement consists of entering the alarm menu and toggling the alarm off. After acknowledgment, any data channel still measuring data outside of its allowed range will still be displayed in red until the data is again within the predefined range. If there are sufficient channels of data in alarm, there will be multiple pages of this menu. Regarding channels in alarm, if any channel is in alarm a red block will appear in the upper corner of the display regardless of the type of screen that is being displayed. This informs the user that a problem exists even if not using the alarm screens.

110. Data display menu. This menu shows two data displays: Programmable Data Display and Scrolled Data Logging (Figure 19). The Programmable Data Display allows display of the last logged value of up to 10 sequential or

randomly selected data channels and allows them to be displayed in user selected order. Data displayed are: MCU number, card and channel identification, the date and time of the measurement, the last logged data, its unit, and the channel message or label. Only the data channel identifier needs to be entered to get the information for that channel. Once data channels are entered, they remain in the display format until cleared by the operator. This is true, even after a power failure, so data channels that were being displayed during a power loss will be remembered and reentered automatically when power returns. Other features of this screen include a demand scan of data and a command to send all data to the system printer. The demand scan command causes a global scan of all MCU's, followed by a poll from the NMS, and an update of all readings from the sensors.

111. The Scrolled Data Logging Display is the part of the menu outlined by a dashed-line box in Figure 19. It will continually display data as it is being logged. This portion of the menu, when first displayed, will have the last collected data displayed on the screen. When the MCU's are scheduled to make their next logging of data, any measurement which is made will be displayed here. As new data arrive, the least current information scrolls off the top of the menu and is replaced by more recent data at the bottom.

112. MCU configuration menus. The procedure for setting the characteristics of each data channel in the MCU is performed under this menu. As mentioned in paragraph 101 there are seven primary submenus, each dedicated to some form of MCU configuration chore. These submenu headings of the MCU configuration menu are:

a. 4.10 Sensor Measurements

b. 4.30 Unit Conversion Computations

c. 4.50 Alarm Configuration Setup

d. 4.60 MCU Outputs and Control Functions

e. 4.80 MCU Configuration Control

f. 4.90 Autodial Telephone Modes

g. 4.99 Generic MCU Configuration Menu

113. Each of the menus beneath these submenus allows configuration of each sensor on a channel-by-channel basis, permitting complete independence of the specification of input type, engineering units conversion, channel sampling rate, channel alarm range and condition, and provisions for further data

processing or analysis of the data. The screens mentioned in paragraph 112 are described in paragraphs 114 through 123.

114. Sensor configuration submenu. This menu is further divided into 14 submenus, each dedicated to configuring one particular type of sensor. The composition of the 14 menus are essentially the same as that shown in Figure 20, and are devoted to configuring sensors which measure: DC voltage, DC resistance, and DC current configurations (with range, excitation, integration time, and sensor warm-up time), vibrating wire (with pluck frequency and duration choices), Carlson strain measurement, Carlson temperature measurement, incremental encoder input, pulse count input, pneumatic multiplexer system input (with flow, gas, and BCD modes), time interval measurement, scanning valve multiport pressure input, thermocouple measurement, and plumbline monitoring.

115. Unit conversion computation submenu. This submenu is further divided into menus which allow user definition of the constants and exponents of nine different types of equations which are used to turn the raw data obtained from the sensors into engineering values. Their form is similar to the type shown in Figure 20 with the conversion equation information at the top, and the evaluations and logging information at the bottom. The user merely inputs the values of the constants and exponents into the appropriate equation and the raw measurement taken from the sensor is converted into engineering units for screen or printer display.

116. One additional menu under the unit conversion computation submenu is a data averaging menu which allows any channel of data to be reported as the average of data collected from that channel over a given period and interval of collecting the data.

117. Alarm configuration setup submenu. This screen provides a means to set alarm limits for each channel of data being collected in the system. The screen allows the user to set allowable extremes of the data for comparison with the data being taken. It also allows composition of a message which will print out on the alarm status screen when a channel goes into alarm, and enables or suspends activation of the optional voice reporting system.

118. MCU outputs and control functions submenu. This submenu is further divided into 13 menus which are intended to issue control commands from the MCU to instruments or other MCU's. The first two submenus, relay and analog output control, are designed to send information to closure switches which

then activate some remote activity. For instance, the relay output control can be used to send an on or off signal to a valve which can be electronically controlled. The valve would open or close depending on the relay command. The analog output control does the same thing, but, in addition to sending an on or off signal, it can send an analog signal which can set levels of some activity at any desired setting, such as raising a gate to a given elevation. While these features are available, they are not presently used at Beaver Dam.

119. The third function of this submenu is a pass-value screen which allows sending data to a channel of another MCU. Using this feature, any MCU can be turned into a repeater unit for other MCU's. Any data passed through this menu will be sent to the MCU where it was directed and can be sent from there to any other MCU over the hardwire or radio networks. This is useful in providing data from one area of the system to another for use in calculations.

120. The fourth screen under this menu allows delaying collection of data on any desired channel for a given period of time. This lets the user delay a reading of a particular channel, dependent on the condition of another channel. This is done through a concept called parent and child relationships. If one considers one particular channel of the data acquisition system the parent channel and wishes to read a number of other channels collecting data related to this channel at a later time (or times), then these other channels can be configured as dependent on the action of the parent channel. For instance, consider a situation where one channel of a data acquisition system is configured to read the height of a column of water. When the water gets to a certain elevation it is desired to wait 15 min for a set of sensors to stabilize and then be read. If the water column sensor is designated the parent channel and the other channels configured as children, then all the channels configured as children can be delayed to be read 15 min after the parent channel reaches a certain value. The advantage of this setup is that all configurations that are children are dependent on the activity of the parent, and if the configuration of the parent is changed, there is no further need to change the configurations of the children. The remaining nine menus allow selection of relays, control of scheduling, control of release gate parameters, flow and positioning requirements, and control of fish ladders. The majority of these are not used at Beaver Dam but exist in the software.

121. <u>MCU configuration control submenu.</u> This menu provides the capabilities of configuring the MCU's and the NMS from the terminal screen. The

first item on the screen is an entry which is headed Function. This allows the user to toggle through eight options that allow listing and printing the current setups, downloading the most recent changes to the MCU's, saving the MCU configuration to the protected special storage areas in RAM, deleting the requirements for reading MCU channels of data, and uploading current configurations from the MCU's for storage in the NMS. This menu has a feature that will allow only one data channel to be acted upon, or many channels that are similar. The * (wildcard) character, which means "act on all elements which occur in this field," provides the capability to act on a multitude of fields that are similar.

122. Autodial telephone modem submenu. One of the options that the system installed at Beaver Dam is capable of supporting is an autodial voice reporting alarm system. The system is designed to accept special hardware that will give voice notification of alarms over the commercial dial telephone network if sensors give readings outside preset ranges. This allows notification of data channels in alarm when there are no appropriate personnel in attendance at the dam. If a preprogrammed sensor exceeds its expected range, this hardware will begin to make a series of phone calls over the dial telephone network to personnel capable of responding to the alarm condition. The hardware can be programmed to call as many as five prioritized telephone numbers. Beginning with the first number, the unit rings 10 times before moving to the next number, proceeding through the list in this manner. If all numbers are called without answer or appropriate acknowledgment, the dialing begins again with the first number. When a number is answered, the system requires a touch-tone acknowledgment code from the part being called to confirm that the contact individual is someone with the authority to act on the alarm information. If the acknowledgment is made, the voice synthesizer delivers a message based on the alarm condition. If not, the next number is called. The system allows for the control-room operator to enable or disable the callout feature depending on whether or not the control room is attended. It is also possible to terminate the callout capability.

123. Generic MCU channel configuration submenu. This menu allows the user to look at and modify the configuration of any channel by entering its channel identifier. Under other menus, modification of a channel can only be done when accessed through a menu related to the type of sensor connected to that channel. This screen displays the channel configuration type, and all

the evaluations and logging data that are shown in Figure 20. The channel can be reconfigured from this menu in the same way as most of the other menus. A special feature of this menu is a "how bytes" line which lets the user configure data channels to do chores which have not been setup by the other channels. This is a programmers configuration menu because it lets individuals do other types of configuration other than what has been "canned" for them.

124. MCU status menus. The status submenu of the main menu reports MCU "system" status conditions as opposed to I/O or user configured measurement and status functions. It reports conditions relating to the proper functioning of the MCU, and maintenance diagnostics for those units. There are four submenu screens which display and allow modifications of the MCU internal conditions and the hardwire and radio networks which connect the system.

125. The first submenu is a display of the internal conditions of the MCU's as of the last reading of their status. Its content cannot be changed, and it gives a report containing MCU address, date and time of last status reading, history since the previous check, a section which reports the version of the software being used in the MCU, the power resets, number of times alarms have been activated, and the number of hardware and software resets. It also has a section which monitors the status of the battery voltages, both main and memory backup, the voltage of the clock/calendar battery, and the temperature in the MCU. A keyboard command from this menu permits a print-out of the above status report for all MCU's.

126. The second menu gives a display of the network performance of the system. For each MCU there are two hardwire remote networks and two standard serial communication lines. This menu displays all activity on both the input and output ends of these four communication channels. The information logged includes: the number of bytes of information passed, control messages, data messages, and retransmission rates. This menu, like the first, cannot be modified.

127. The last two screens are set-up screens which allow the configuration of the temperature sensors inside each MCU and configuration of communizcations information. They are modifiable and are similar in design to that of Figure 20.

128. Network topology menu. This submenu of the main menu is one which is not used on a daily basis but is necessary to allow the flexibility with which the MCU/NMS/terminal network system operates. This menu defines the

other system components with which each component in the system can communicate and through which means. This type of "map through the system" lets each remote piece of equipment connected to the system communicate with every other one, regardless of whether or not there is a direct connection. With this capability, data can be shared between all MCU's in the system without overlap or redundant effort.

129. This screen would normally be accessed only if the configuration of the system had changed, such as an MCU or remote unit added to or subtracted from the system. Then, each surrounding piece of equipment would need to be reconfigured to reflect the changes that had been made.

130. Issue orders and view traffic menu. This menu is one that allows the execution of 15 system commands that can change conditions over the entire system or only one channel on one card in the system. The effect of these commands on the system range from setting the system clock to resetting all memories in the system to the default settings.

131. Satellite transmitter. The last menu accessible from the main menu is designed to be used to set up the parameters for transmission of data over a GOES satellite transmitter. Parameters such as window size, frequency of transmission, and amount and type of data are configured here.

132. Remote access to the system. All features of the system that are available to the user at the NMS (located in the dam powerhouse) can be accessed at remote computers over dial telephone lines. Not only are all the system commands and menus available to the remote user, he or she sees the same screens and information as would a user at the NMS. This is possible through a communications software package called Carbon Copy®. This software, and several other packages like it on the market, display the same information on the screen of a remote terminal as is shown on the screen of the host computer. This is possible because the Carbon Copy® software is installed on both computers (the host at Beaver Dam and the remote terminal), and the information that is passed from one display to another has been coded so that both screens can properly decode the information and properly redisplay it.

PART III: INSTALLATION AND OPERATION

Preplanning

Materials

133. Planning process. In a demonstration program, all aspects of the work conducted must be covered to give a complete picture of the efforts that are necessary to install a successful system. The installation process, itself, is a vital part of this process and needs to be emphasized. Indeed, a properly functioning instrumentation automation system will not become a reality unless adequate attention is paid to the installation process.

134. Installation planning begins when the physical layout of the instruments and controllers has been decided. At this time, such things as adequate space allocation, lengths and amount of cable, type of cable, need for conduit, special housings for instruments, routing of wiring, and other items to be ordered or planned for must be considered.

135. For the concrete dam portion of the demonstration project, this meant determining the amounts and types of cable for eight pressure transducers, four Carlson strain meters, one scanning pressure valve system, and one water level encoder. Each type of instrument uses cable with a different number of conductors in it, so purchase of several types of cable were needed. Study of the intended instrument layout revealed the lengths of each type of cable needed and showed any locations where special care of the cable needed to be taken to prevent damage to the cable.

136. The MCU which was purchased for the concrete portion of the dam was to be placed in a relatively humid environment, so provisions had to be made to house it in an NEMA rated cabinet to prevent damage from the moist environment.

137. Other items should be ordered ahead of time so that the installation operations would go smoothly. Special adapter plugs, mentioned in paragraph 59, were necessary to modify the uplift pressure pipes so that their water pressures could be ported to the scaning pressure valve without removing the capability of reading the gages manually. Hardware, such as high-pressure nylon tubing and microclamps to secure the high-pressure tubing, was needed to complete the inventory of parts for the scanning valve system.

138. To determine the flow of water through the dam's gutter system, a

series of eight V-notch weirs had to be built that matched the dimensions of the gutters at the locations where the flow was to be measured. Along with this requirement, there was a need for frames to mount the weirs and special templates used for periodic calibration of the water pressure transducers behind the weirs.

139. Normally, Carlson joint meters are embedded in concrete. For this installation, they were attached to the walls of the gallery. Suitable angle brackets had to be frabricated to mount the meters so that they would not record strain other than that due to crack movement.

140. Quality. All materials used in a moist environment should be of the best affordable quality. This includes cable, wire, instruments, computer equipment, and hardware associated with the installation. Because corrosion in a moist environment will drastically reduce the life span of most materials, it is not a wise decision to save a little money by purchasing inferior quality materials or components.

141. All electrical materials which were used were specified to comply with the current standards of American National Standards Institute (ANSI) C80.1, National Electrical Code (NEC), and the NEMA wire and cable standards.

142. All metal parts, such as screws, bolts, and nuts exposed to continually wet conditions, were either stainless steel or brass. Dissimilar metal contact was avoided wherever possible.

143. Instruments. Since all of the instruments installed under the demonstration were commercially available products, they were specified to be constructed of materials which would hold up under the environment in the dam. For instance, all pressure transducers for installation underwater were specified to be constructed from stainless steel. All Carlson meters are sealed by a series of O-rings to preclude moisture from their interior, and the housings are all made of brass. All components of the scanning pressure valve are expected to be in contact with water continuously. They were specified to be stainless steel or brass.

144. Wire and cable. All wire and cable were specified to be round in cross section and to have an American Wire Gage (AWG) wire size designation. There were several types of wire used, and sizes were determined by use in the project. All wire carrying line power was designated to be No. 12 AWG; all low current and low voltage carriers were specified to be No. 18 AWG; signal

wire was required to be No. 20 AWG, twisted-pair, stranded wire with 100 percent of the pairs individually shielded; and all signal carriers over the hardwire RAN were specified to be No. 24 AWG. It was further specified that all wire suitable for installation in the vertical (wire traveling up or down an access shaft or elevator shaft) have coverings or insulation which would not be injured when supported as required by the NEC.

145. Conduit and associated hardware. Conduit was specified to be used to house wire and cable when the wire could be damaged by physical or environmental means. All materials for electrical conduit were specified to current Federal specifications. For rigid steel conduit, Federal Specification WW-C-581E and ANSI C80.1 were cited, and metal conduit fittings were to conform to Federal Specifications F-W-406B and F-W-408C. Any exposed outlet bodies or boxes were to match Federal Specification W-C-586B, and junction boxes, extensions, and covers were to meet Federal Specification W-J-800C(1). The care used in bending, cutting, and installing metal conduit was also important and proper techniques to ensure such were specified. All conduits were required to be supported at intervals not greater than 5 ft and rigidly tied to walls or ceilings by screw-type anchors. Any bends in the conduit were to be made using the proper radius bending tool to ensure that the bends were smooth and would not be kinked, flattened, or dented. All burrs or sharp edges resulting from cutting the conduit were removed so that wire being pulled through the conduit would not be damaged. Bushings were installed on the ends of all conduits to further protect the insulation on the wire.

Tools and installation equipment

146. Every installation will present different needs for tools and equipment. It is important to identify which tools are needed before the installation begins, so that all hardware can be purchased, accounted for, and checked for proper operation prior to their need. The installation in the concrete portion of Beaver Dam consisted of installing one MCU, the sensors previously described, the associated hardware such as weirs, the conduit, cable, and wiring to connect the sensors to the MCU. In addition, the MCU in the dam had to be wired to the main MCU in the powerhouse. The tools and equipment listed are those which were necessary to complete the Beaver Dam installation:

Tools and Equipment in Beaver Dam Installation

Electrical tool kit	Masonry type drill	Flashlights
Soldering iron	Extra drill bits	Tape measure
Saber saw	Electric hand drill	Wrenches
Extension cords	Cable dispensers	Hammer
Wire splicing kits	Cable marking tags	Screwdrivers
Nylon tubing, 1/8 in.	Cable clamps	Carpenter's square
Wall anchors	Cable ties	Level
Tubing sleeves	Caulking compound	Files
Electrical tape	Pipe cutters	Hacksaw

147. Most of the equipment mentioned is standard for conducting wiring installation in a concrete dam. The masonry drill and bits are a necessity for creating inserts in concrete to accept screw fasteners. An alternative piece of equipment to fasten items to concrete or steel walls is a stud gun. It rapidly shoots threaded studs into the concrete or steel, and the stud is anchored to the wall by gripping teeth in the base of the stud. This piece of equipment is expensive, but on a large installation it would save much time and labor.

148. The saber saw was necessary to custom fit the weirs to the gutters at the installation point. The nylon tubing was necessary to connect the scanning pressure valve to all of the uplift pipes. The pipe cutting equipment is necessary to size conduit, and the files were used to prepare cut ends of conduit so that they would not damage cable and wire insulation. Most of the carpentry tools helped complete the job of fastening wire and conduit to the walls and floor. The carpenter's level was used to install the calibration fittings for the weir transducers. More complicated jobs will require more equipment. If conduit must go around corners, then tube bending equipment will be necessary to properly bend the conduit without kinking it or otherwise hampering the process of running cable through it.

Sensor Installation

Hardware components

149. Weirs and pressure transducers. The installation of these

instruments and hardware was a straightforward process. The first chore was to locate the general area in the gutters where the weirs would be placed. Any debris, sediment, or deposits were thoroughly removed from this area in order to ensure a clean site for installation of the weirs. A weir frame was first fastened into the gutter to provide a support for the weir. It was fabricated from aluminum angle iron shaped to fit across the bottom of the gutter. It was secured to the bottom of the gutter with concrete inserts and screws. The frame is a permanent installation, and before it was installed, a strip of rubber was set on the concrete to provide a seal between the frame and the concrete. It was then caulked into the gutter. A photograph showing a completed weir frame is shown in Figure 21.

150. The weirs themselves were also caulked into the frame to ensure that the only flow past them was through the weir opening. They were fabricated from 1/4-in. nylon sheet, slightly larger than the dimensions of the gutter so that they could be custom fit to each location and weir frame at the time of installation. This precaution is always advised because "as is" conditions generally differ from construction drawings. They were set into a continuous bead of caulking in the frame and clamped until the caulking had set. Several measurements were taken to be used in the calibration of the

Figure 21. Completed V-notch weir showing aluminum base angle

weirs and their transducers. First, any slope in the bottom of the gutters behind the weirs was measured, secondly, the height of the bottom of the V-notch above the bottom of the gutter at the weir was measured. These two constants were used to establish the height of the transducer above the bottom of the gutter.

151. The transducers were mounted at least 12 in. upstream of the weirs. This distance was necessary to be certain that the free surface of the water flowing over the weir was actually representative of the head of water flowing in the gutter. At distances closer to the weir than four times the maximum head of the water above the crest, the total head is influenced by surface drawdown, and measuring this head would be inaccurate. The distance of the transducer upstream from the weir was also accurately measured at this time. The transducers were mounted to plexiglass mounting and calibration plates on the wall side of the gutter, as shown in the sketch in Figure 22. The transducer was mounted so that its sensing element was a known distance above the bottom edge of the mounting plate; and the mounting plate was placed on the bottom of the gutter. This established the distance between the bottom of the gutter and the sensing element. The mounting plate is fastened to the wall through slotted holes in the plate (Figure 22). These holes allow the plate and the transducer to be raised for calibration purposes. With the mounting plate in the measuring position (bottom of the plate on the bottom of the gutter), a second piece of plexiglass is mounted with its bottom edge exactly 3 in. above the top edge of the mounting plate. When calibration is to occur, the bolts on the mounting plate are loosened, and it is raised the 3 in. until it comes in contact with the fixed upper plate. A reading can then be taken both in the raised and lowered positions for a calibration of the output of the sensor. A photograph of the final installation is shown in Figure 23.

152. The pressure transducers for the weirs are sent from the factory with 6 ft. of waterproof lead cable. This cable was cut to an appropriate length and fastened to the wall of the gallery to avoid any damage. The cable transmitting the signal from the transducer to the MCU was then spliced onto the lead cable. The splice was protected against the ingress of moisture by the following procedure. Each individual wire in the lead cable was soldered to the appropriate wire in the transmission cable. Heat shrink tubing was then shrunk over each soldered joint, and a layer of asphaltic, moisture-barrier

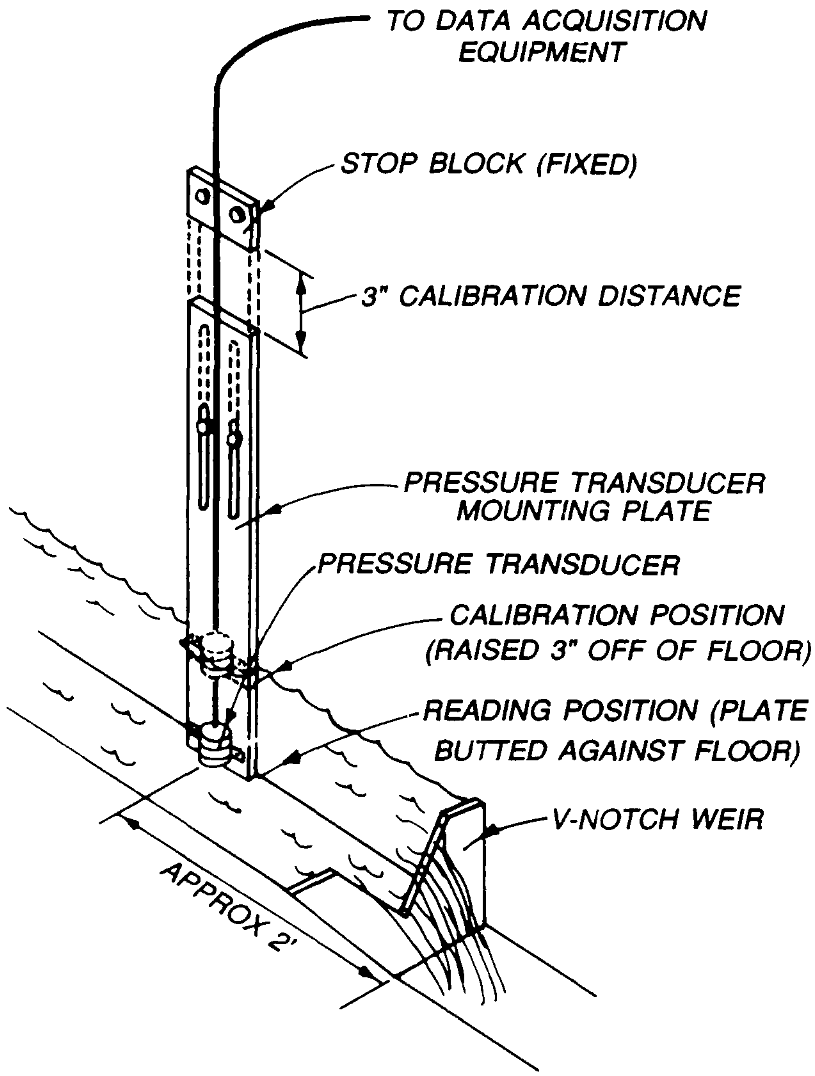


Figure 22. Sketch of the weir transducer measurement/calibration setup

tape was tightly wrapped around the wires. The whole splice was then wrapped in plastic electrician's tape to complete the splicing technique. To allow atmospheric pressure to the back side of these gages, the end of the vent tube from the pressure transducer was allowed to protrude through the splice. A more secure epoxy splice was not used in this instance because of the inside environment.

153. The question of what to do with water flowing in the gutters during the installation was one that had to be addressed before work could begin. Drilling holes in the concrete with an electrical drill with water in the vicinity of the drill is dangerous and should not be attempted. Additionally, caulking joints underwater is difficult, and less certain than if the area is

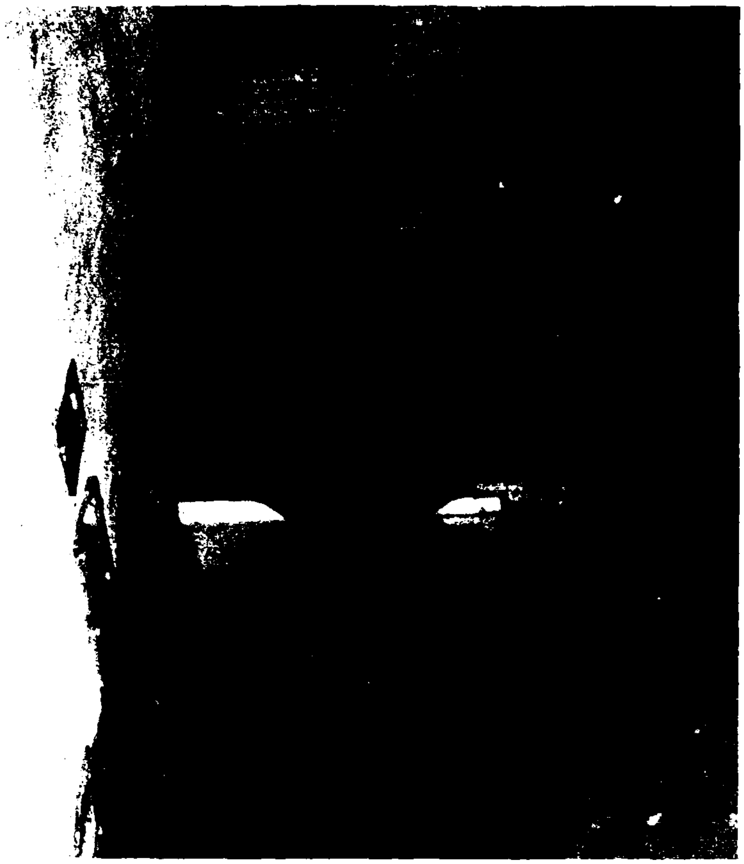


Figure 23. Completed V-notch weir showing location of gage and calibration plates

dry. To alleviate the wet situation, the gutters were dammed above the work area, and the water diverted into the opposite gutter. This provided a temporarily dry area in which to work.

154. Exterior weir. One pressure transducer, the same as those installed behind the interior weirs, was installed behind a weir at the foot of the main embankment adjacent to the concrete portion of the dam. Figure 24 is a photograph of the weir as it looked before the pressure transducer was installed. A new knife-edge weir similar to those installed in the dam was installed over the weir shown in this photograph. The pressure transducer was mounted to a metal plate that was mounted on the inside of the concrete wall shown in Figure 24. This transducer has the same capability to be calibrated as the pressure transducers in the gutters in the dam.

155. As can be seen in the photograph, there is a significant amount of algae in the water in the sump. This algae was removed by scraping the majority of it out of the sump and adding an algaecide to the water to prevent

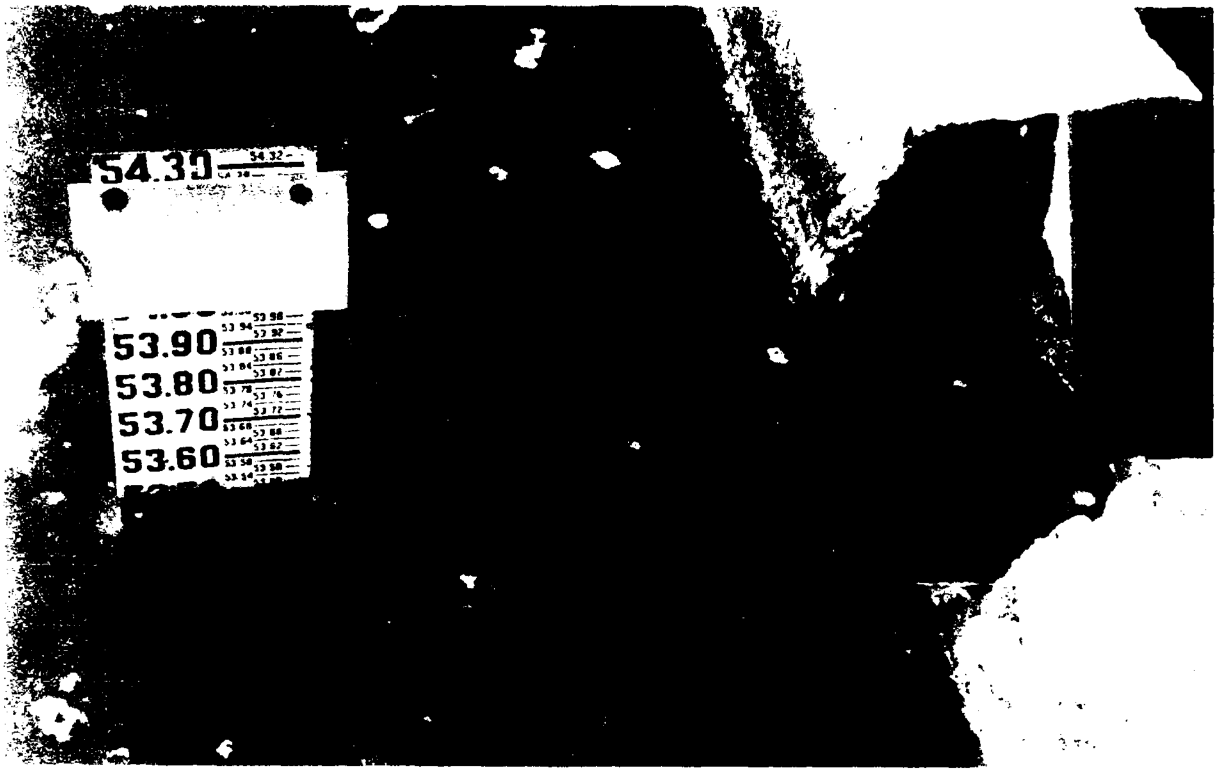


Figure 24. Condition of exterior weir before pressure transducer installation

additional growth. Since algaecides lose their potency with time, their continued ability to prevent marine growth will diminish, and the algae will grow on the walls, the weir, and the transducer. If the sensing face of the transducer becomes plugged with algae, the data it sends back to the MCU will be erroneous. This is an area within the system that requires good periodic maintenance to make sure that the system is properly functioning and producing valid data.

156. Carlson joint meters. The Carlson joint meters were installed directly over the cracks to be monitored. Since these meters were mounted externally and not embedded in the concrete as joint meters usually are, they had to be attached to the wall by means of L-shaped brackets which were attached to the end of the meter and fastened to the wall. A sketch of these brackets is shown in Figure 25. The Carlson joint meter comes with a flange on one end, and a male threaded stud on the other. The right end bracket shown in this figure was fabricated with a threaded hole to match the threaded stud on the end of the Carlson meter. This bracket was attached to the wall first, and the Carlson meter threaded into it. The L-shaped bracket for the

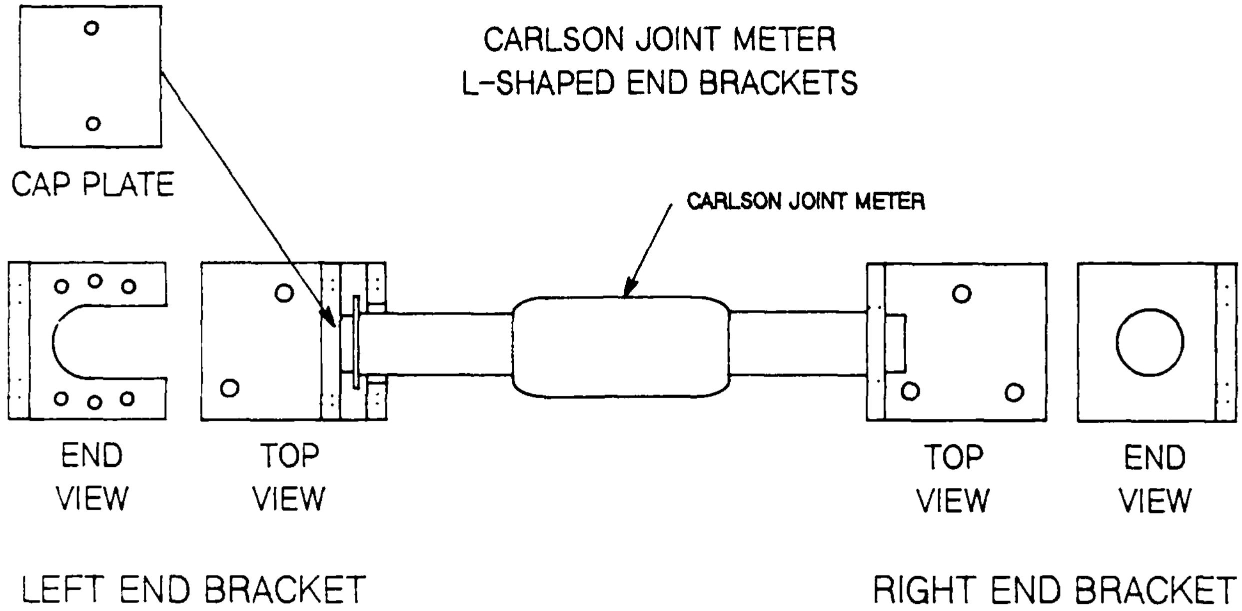


Figure 25. Sketch of L-shaped brackets used to secure Carlson meters to wall

other end of the meter was designed to fit around the body of the joint meter with the flange of the meter to the outside of the bracket. It was positioned around the Carlson meter and then fastened to the wall. This bracket is fabricated with six small screw holes in the arm of the bracket which surrounds the joint meter. Four screws which fit into these holes were designed to contact the flange of the Carlson meter to put the meter in a small amount of tension when it is first installed. This tension provides a positive reading on the meter and allows for continued positive reading in the event that the crack should attempt to close. This will ensure that there is always tension on the meter and always a strain reading. These four screws are also individually adjusted to ensure that the joint meter is always axially loaded. The final portion of the bracket shown in this figure is a cap plate which screws over the flange of the Carlson meter and into the L-shaped bracket. This cap was used to immobilize the flange of the joint meter if the crack tries to close. Two meters were attached across each crack as shown in Figure 26. The cables were attached to the gallery wall and spliced to cable running to the MCU's in the same manner as for the weir transducers.

157. Uplift pressure scanning valve. Before the scanning valve could be interfaced to the present uplift pressure measuring system, a means of accessing the water pressure in the uplift pressure pipes had to be

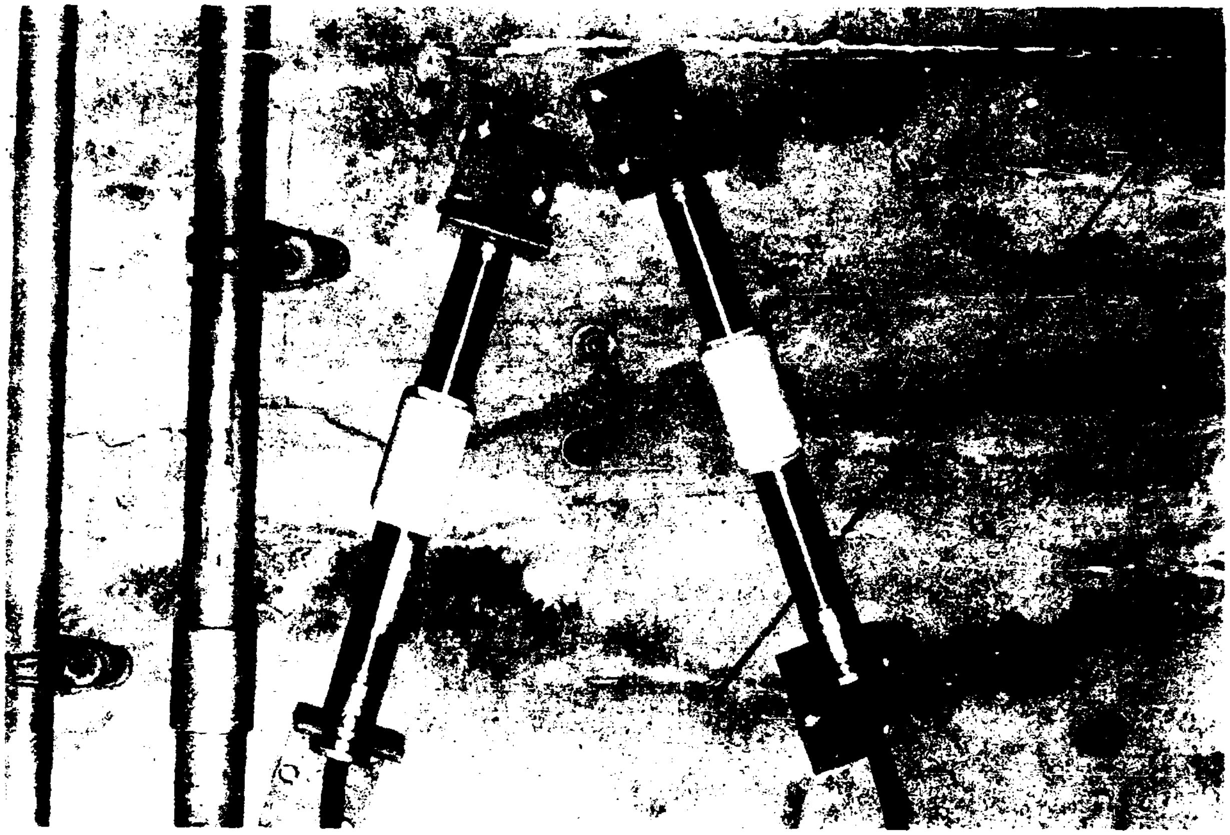


Figure 26. Photograph of the two Carlson joint meters across the crack in monolith 16

implemented. This was done as described in paragraph 59. The hydraulic lines from the pressure gage valves to the scanning valve are high-pressure nylon tubing of 0.06-in. inside diameter. The nylon pressure tubes were gathered in a group and routed from the individual pressure pipes to a central location in the inspection gallery where the scanning valve is located. A central location for mounting the scanning pressure valve was selected to minimize the length of tubing from each uplift cell to the scanning valve, and to minimize the length of electrical wire from the scanning valve to the MCU. Each tube connects to one of the input ports of the scanning valve. Since these lines can contain high water pressures, they must be secured to the input ports of the scanning valve via special clip springs which hold the nylon tubing to the input port.

158. The output line, running from the scanning valve to the MCU, is a two-wire twisted pair that connects to the special I/O card in the MCU

designed to read the BCD output of the scanning valve. This cable is attached to existing conduit in the gallery and run back to the MCU in the dam.

159. Tailwater encoder. At Beaver Dam, the existing tailwater recording device is located in an instrument closet in the powerhouse control room. It is a Leupold and Stevens model ABP recorder. Before attempts were made to adapt it to report its signal to the MCU, there were three forms of output of tailwater elevation. The main form of output was a numerical display generated by a set of gear-driven wheels directly connected to the tailwater float. One encoding device, already attached to the main gear on the recorder, sent a digital copy of the output signal to a display on the main power generating panel in the control room. The final method of outputting the elevation was by means of a strip chart recorder attached to the Stevens equipment.

160. To provide a signal to the automated data acquisition system and not disturb the other encoder, a second encoder had to be inserted into the system. The installation procedure required the temporary removal of the existing encoder to insert the new encoder into the system. With the existing encoder removed, a new platform to hold the two encoders was installed, and the new encoder was connected to the main gear of the Stevens recorder. The new encoder has a dual shaft which allows the old encoder to be attached to one side of the new one, and as a result, both encoders turn in direct relationship to the main Stevens recorder gearing. The old encoder was then reinstalled on the shaft of the new encoder.

161. The chain drive from the Stevens recorder had to be reset and adjusted to ensure delivery of correct information to the two encoders. This was accomplished by referring to the master reference numbers on the Stevens recorder, and rotating the drive gear of the encoders until the output matched the reference output. The chain was then replaced on the drive wheel, and the modification completed. A picture of the completed encoder setup is shown in Figure 12.

Cable

162. Prior to installing any of the transducers, the cable that would carry their signals to the MCU was laid out. It is important to provide sufficient splice-free cable from sensor to data collection point to eliminate any signal deterioration that may occur at splices. Cable was always attached to the walls of the galleries, and in most cases, it was secured to existing conduit. Where multiple cables were strung along the same length of gallery,

the cables were bundled together with cable ties and then tied to the existing conduit. All cables were identified at each end with a cable identification number, and all wires within each cable were color coded so that proper connection to the correct terminals would be easily achieved.

163. Running cable in galleries that are sometimes thousands of feet long can be simplified if the proper tools are available. At Beaver Dam, the amount of wire that had to be laid out was not significantly large. The method of paying cable from cable reels was accomplished by mounting the cable reel on a piece of pipe, anchoring the cable at one end of the run, and then walking the reel to the other end of the run. This could be accomplished by one or two technicians. However, if many sections of cable are to be strung along the same length of gallery, a more sophisticated cable paying cart can be used which will allow one technician to string many cables at the same time.

164. Where the cable could not be attached to existing conduit, it was attached to the wall by means of special cable ties which can be screw-fastened into the walls. Figure 27 shows both methods of attaching cable to

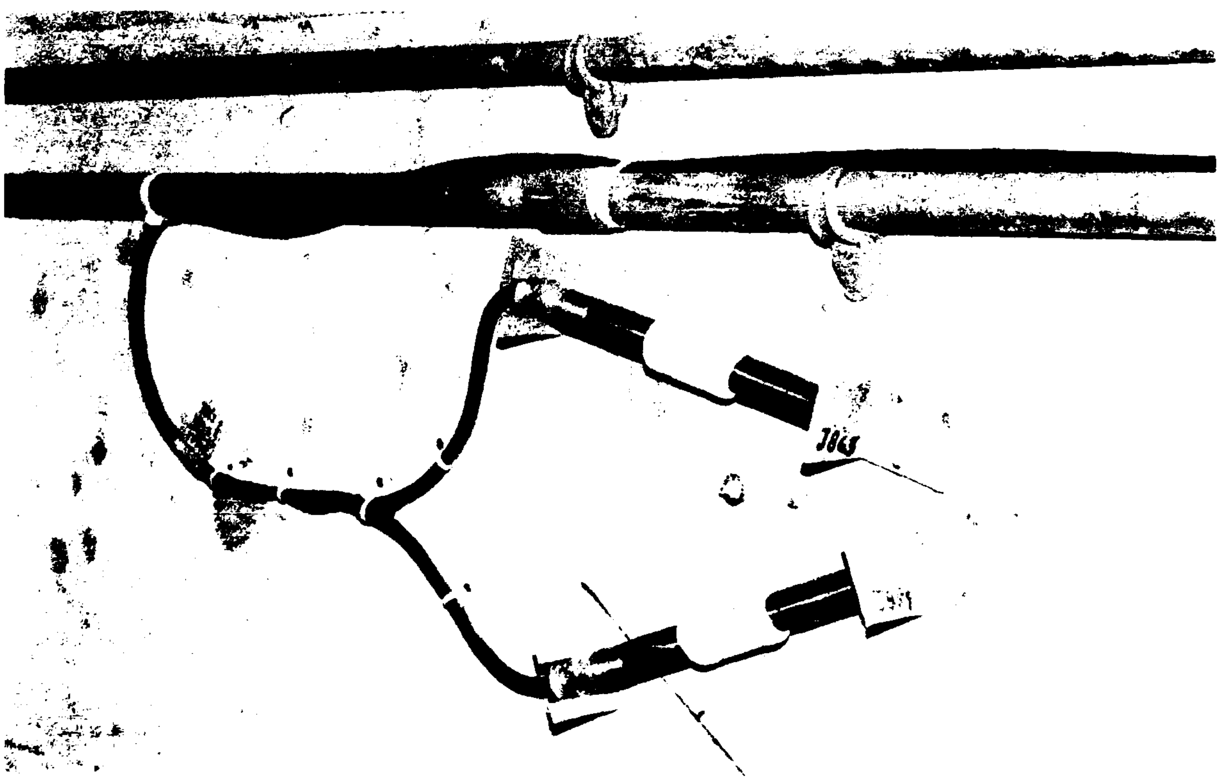


Figure 27. Photograph of cable to two Carlson joint meters showing the method of attaching cable to the wall

the walls and conduit. Immediately adjacent to the ends of the two Carlson meters in the figure, the cable is attached directly to the wall, while just above it the attachment is to the existing conduit. If conditions warrant, the cable can be strung through the conduit. To have done that in this instance, the conduit would have been opened at the joint, and a T-coupling inserted at the joint that would have allowed pulling the cable into the conduit.

165. The cable from the pressure transducer installed behind the weir below the main embankment had to be run approximately 550 ft to get back into the dam. Since this cable was outside, it was placed in conduit or buried in a trench to route it back to the dam. Figure 28 shows the area adjacent to

Figure 28. Cable trench running from the exterior weir

the weir that was trenched to bury the cable. The lead from the transducer at the weir was placed in conduit, and the conduit run until it met the trench. The cable ran approximately 100 ft buried in the trench shown in the figure, and then was routed through some existing conduit back to the dam. At the transducer where the cable entered the conduit, the entrance was sealed against water by a mastic plugging material.

166. The cable between the MCU in the dam and the MCU in the powerhouse is twisted-wire pair cable. This cable is routed from the MCU in the dam, along the gallery walls, to an existing conduit that runs from the dam to the powerhouse. The twisted-wire pair was pulled through the conduit into the powerhouse and run to the RAN interface on the back of the MCU in the powerhouse.

MCU

167. The MCU in the dam was mounted in a wall recess in monolith 10 (Figure 3) at the upper level of the drainage gallery. It was checked for operational readiness at the US Army Engineer Waterways Experiment Station (WES) before being brought to the dam, so all that remained for its installation was to mount it in the NEMA cabinet, connect the sensor cables, and wire it to the MCU in the powerhouse. The NEMA cabinet is shown in Figure 29. The cabinet is hinged in two planes, allowing access to all faces of the installed MCU. This type of design is important when removing wires or cards or servicing the MCU, because it allows the technician to work from the front or the back of the unit. All sensor cables enter the NEMA cabinet from the top or the bottom of the cabinet. The cabinet was provided with rows of 20 punch-out holes both top and bottom to accommodate the cable. Each cable entering the cabinet was outfitted with a water-tight grommet to seal the punch-out from moisture. The punch-outs that were not used were not opened.

168. The cabinet was outfitted with an outlet box into which a socket was plugged to install the light bulb shown in the figure. Even though the NEMA cabinet is moisture proof, a small wattage light bulb kept burning was used as insurance to keep the environment dry. The completed MCU is shown in Figure 30.

System Checkout

169. The proper method of checking a system is to run each component

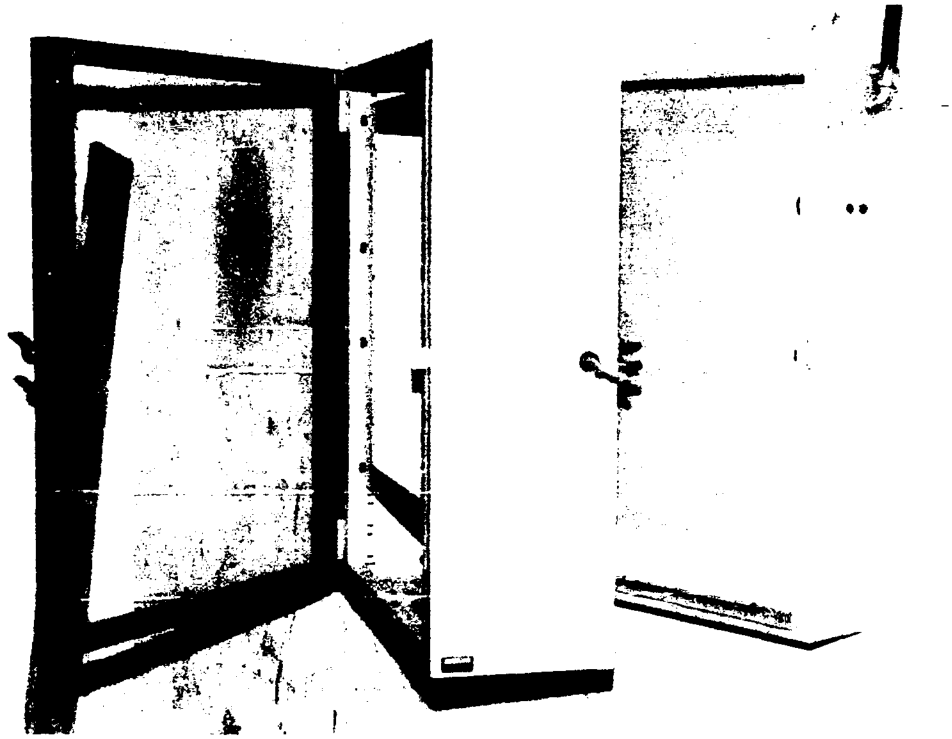


Figure 29. NEMA rated cabinet into which the MCU was installed

separately to find out if it works properly, and then to run the system as a whole. In this manner, if a component is faulty, it will not damage other components by sending improper voltages to components which might be damaged by such. Also, by checking each component, the location of the problem is identified at the component level first. This procedure was followed for the Beaver Dam demonstration. All sensors were checked before they were connected to the MCU's. All MCU's were checked and run prior to being connected to the NMS, and the NMS and all the peripheral equipment were all checked individually before they were connected to the system. Once all the individual components checked out correctly, the completed system was powered and checked as a whole.

170. One of the problems which was encountered during the checkout phase was the discovery of a missing chip on one of the I/O boards. Eight of the weir measuring transducers were connected to the MCU in the dam, and the remaining one was connected to the MCU in the NMS unit because the cabling requirements were shorter to reach this MCU. During the checkout, when viewing the printout screens, it was noticed that the output from the weir

Figure 30. MCU installed in NEMA cabinet

connected to the MCU in the NMS was grossly in error. The sensor was checked and found to be working properly. The interface card in the back of the MCU was examined, and a conversion chip which accepts 4 to 20-mA input to the standard multiplexer input board was found missing. When the board was first specified, there were no plans to input 4 to 20-mA sensors to this card. However, during the installation when it was found less expensive to connect the weir sensor to this I/O interface, the need for the conversion chip was overlooked. A chip was ordered, and the checkout completed without further problems.

171. All segments of the hardware and software were checked in a similar manner, and all system problems were solved on a case-by-case basis. When the system was fully checked, the sensors were calibrated.

Calibrations

172. Sensor calibration, as opposed to output calibration, was conducted before the sensors were put into place. At that time, each of the sensors were tested to be sure that their output reflected the proper value of the measured quantity. The calibration performed after the sensors were installed was to adjust for installation inaccuracies. In changing sensor output from voltage or current values to usable engineering values, a set of mathematical formulas are used. These are theoretical calculations based on the assumption that all input to these formulas are accurate. However, when sensors are installed, there are often differences between the physical and the theoretical which make the output from the formulas inaccurate. The formulas used in the software to convert voltage and current output into engineering output can be modified to take these installation inaccuracies into account. To do this, an output calibration is performed which will relate the mathematical output to a calibrated physical output.

Weir calibration

173. This procedure was necessary for a number of sensors installed in the demonstration program. In the case of the weirs, a set of readings were taken by the data acquisition system, and were adjusted by comparing them to a field calculation of the flow over the weirs using a cylindrical container and a stopwatch to determine the flow. Readings were taken by the data acquisition system using the formulas based on flow theory and field dimensional measurements made when the sensors were installed. Immediately after the collection of that data, the actual flow over the weirs was determined.

174. Actual flow was obtained by placing a cylindrical container beneath the water which was spilling over the weir, and starting a stopwatch at the same time. When the cylinder was nearly full, it was removed from the column of water spilling over the weir, and the stopwatch stopped. The time was recorded, and a measurement of the depth of the column of water in the cylindrical container was taken and recorded. This procedure was repeated five times so that flow calculations could be based on an average of these field readings. The volume of water in the container was calculated based on the height of the column of water and the geometry of the container. This, coupled with the time it took to collect the sample, produced the flow over the weir. These flow calculations were averaged to get the actual flow.

175. These calculations were compared to the output from the data acquisition system, and the formulas used to calculate that output were modified to reflect the values of the actual flow.

Uplift pressure calibration

176. In the case of the uplift pressure transducers, the pressures that were sensed at the scanning valve were generally different from those determined by manual means at the uplift pressure reading cutouts. This is due to an additional head loss or gain that is integral to the pressure sensed at the scanning valve due to a difference in elevation between the uplift pressure cutout and the sensor in the scanning valve. This elevation head is added to or subtracted from the theoretical calculation of uplift pressure. It was determined by taking a set of uplift pressure readings using the data acquisition system, and comparing them to the readings taken manually at the reading cutout. The head difference was then applied to the theoretical value to make them agree. It could have been found by measuring the elevation difference between the two measurement points as well.

177. Since monitoring the uplift pressure is generally valuable to detect changes in the pressure, it might be argued that the modification of the data acquisition system output was not necessary. One could use a new base value taken when the system was installed and compare all future output to that value. However, for the sake of historical comparisons, the readings were referenced to the uplift pressures at cutout elevation.

Piezometer calibration

178. For determining the elevation of the free water surface of all of the vibrating wire piezometers, the sensors were lowered to the bottom of each well and then raised 1 ft. By noting the number of feet of cable that had been played out, the approximate elevation of the sensor could be determined. Knowing this and the head of water over each sensor, the approximate elevation of the free water surface in each well could be determined and programmed into the calibration equations that convert the vibrating wire frequency into free water elevation.

179. The depth of the free water surface of each piezometer was also checked by using an M-Scope to sense the depth. The equations that the data acquisition system uses to determine the free water surface were then adjusted to agree with these findings.

Carlson joint meter calibrations

180. No calibration adjustments were made on the Carlson joint meters used to determine crack movement, since this measurement is taken relative to a base of zero when the meters were installed.

Operation

Data collection

181. Since the system is capable of generating massive amounts of data, the station options menu described in paragraph 106 is set up to categorize data into classes and determine where each of the resulting classes report their data. Figure 31 shows the logging classes of data and where data are sent. A "Y" in the matrix activates data transmission to the appropriate destination.

Level: 1.2 STATION – Station Options – Datalogging Class Display

Destination:	Logging class			
	Normal	Summary	Detail	Diagnostic
Printer	[Y]	[Y]	[Y]	[Y]
.LOG file	[N]	[N]	[N]	[Y]
.HIS file	[Y]	[Y]	[N]	[N]
Log screen	[Y]	[Y]	[Y]	[Y]

F1=EXEC F2=MAIN F3= F4= F5= F6= F7=HELP F8=EXIT

Figure 31. Logging classes for system collected data

Four classes of data

182. All four classes of data are logged to the printer and the CRT screen. Data transferred to the screen are for immediate viewing only and require no storage space. Since the system is newly installed, it is appropriate to check on the validity of all output. Rather than saving it all to

disk storage, printing it to paper allows reviews without taking up valuable disk storage space. Data put in the normal and summary classes are also saved to a history (.HIS) file. These are compressed versions of printout data that are stored on magnetic media. Figure 32 shows 5 lines from a typical .HIS file. In these files, each line of data represents all the necessary data to describe one reading. The data sometimes run together, but knowing how many columns are devoted to each item allows one to decipher the information. The first 4 columns represent the MCU ID, the next 8 represent the card, channel, and type of measurement conversion, the next 14 denote the date, the next 16 hold the actual data with the assigned dimension, and the last 24 hold a descriptor of the user's choice.

```
WES10108AXBC19880303040425   1.38528gpm weir 8, W gutter ph adit
PP  2101IEI 19880303040100   1119.62feet Lake elevation
PP  2102IEI 19880303040100   919.550feet Tailwater elevation
ME  0101AXBY19880303050002   1067.68feet ME-1A
ME  0102AXBY19880303050032   1037.63feet ME-1B
```

Figure 32. Section of output from an .HIS file

183. Diagnostics are generated by the system when there is a problem. If there is no attendant at the system console when such a message is printed, it will be lost. These messages are stored in log (.LOG) files that can be viewed at any time to determine the time of the diagnostic and the nature of its meaning.

184. Reading schedules. The frequency at which data are collected is a function of the type of data being collected, and the urgency with which the data are needed. As a result, each set of instruments has its own reading frequency and logging class. Table 1 gives the reading frequency and logging class for the instruments being monitored at Beaver Dam. Piezometers are read every 8 hr to help keep track of ground-water changes due to variations in pool elevation. Barometric pressure cells (instruments used to collect part of the information needed for the piezometers) are read every hour and the information is passed along to the MCU's. When the piezometers are read they use the latest barometric pressure available in the calculations. The rain

Table 1

Reading Frequency and Logging Class for Beaver Dam Instrumentation

Instrument	Reading Frequency	Logging Class
Piezometers	Every 8 hr	Normal
Gallery weirs	Every 12 hr	Normal
Crack monitors	Daily	Normal
Uplift pressure gages	Daily	Normal
Pool elevation gages	Every 6 hr	Normal
Barometers	Hourly	Detail
Rain gage	Every 6 hr	Normal
MCU batteries	Every 12 hr	Detail

gages are read every 6 hr, and an accumulative display of the 24-hr rain is displayed.

185. The conditions affecting the above instruments can change at any moment, and must be monitored more frequently than the crack movement instrumentation. Monolith crack movement is likely to be of two types, daily movement due to daily temperature fluctuation and yearly due to annual temperature cycles. These instruments are monitored on a daily basis to detect both types of movement, particularly to provide a yearly time-history of the crack movement. Likewise, uplift pressure, under normal conditions, will change with the change of the pool elevation. This information is collected on a daily basis to keep a long-term history of changing foundation pressures.

186. Gallery flow is being read each 12 hr to establish the current flow rates from the various areas of the dam that are now defined by the weirs. The headwater and tailwater gages are read four times daily, keeping track of head changes due to power generation requirements. The MCU battery voltage is important to keep the remote MCU's running. They are monitored on a 12-hr schedule to keep track of the solar recharging rate. They are read at noon to monitor the battery voltages when sunlight is a major factor and again at midnight when the battery voltages are not affected by the solar charging.

187. Data storage. On a daily basis, the data are transferred to disk storage. As measurements are taken during the day, those that have been

selected for retention are stored in RAM storage. At midnight all the days data are transferred to an .HIS file and the RAM purged of the data it was storing. The system then starts the next day's collection of data. Those data that are destined for .LOG files are handled in the same way.

188. Obtaining system data. On a daily basis, the system runs itself. There is no need for a remote operator to interact with the computer to collect data. However, if the user wants to change a parameter or download data to the District office, a remote log on to the system is necessary.

189. The instrumentation personnel at the US Army Engineer District, Little Rock, who are responsible for managing the Beaver Dam system generally collect data from the system on a daily-to-weekly basis. The information in the .HIS files is transferred back to Little Rock. The remote user calls up the system and obtains access to the computer operating system, and from there they can call back any .HIS file. Generally they call back the one from the previous day, but an entire week of files can be retrieved. At present, the data must be retrieved manually. However, future generations of the communications software used by the system promise to contain code that will allow that chore to be done automatically.

190. Data reduction. The data returned to the District office is reduced for plotting on a Harris computer. The code used looks at the data, strips all information relating to date, time, and sensor identification from the files retaining this information for future use, compares successive readings and discards information which is not significantly different from the previous reading, and stores it in a plot file with the identification data removed from the file retrieved from Beaver Dam. Plots are usually generated on a weekly basis.

Documentation

Necessary documents

191. System documentation and training. A large instrumentation automation system will become a confusing compilation of wires, instruments, and controllers without the aid of good documentation describing how the system is configured, how it works, and what its maintenance needs are. It is imperative that such information be placed in manuals and kept with the system. Operation and maintenance personnel, system users, and new engineering

staff not familiar with the system must have a good reference for understanding how its works and how to isolate problems that may arise. The installation contractor for the system was required to provide the documentation and training described in the following paragraphs to fulfill this need.

192. System block diagram. A contractor produced block diagram (Figure 5) showing the system organization and the relationship of one piece of equipment to another is a basic necessity. This diagram shows the NMS and all peripheral equipment attached to it, the MCU's, and their associated sensors. The system diagrams should be supplemented by component block diagrams such as those shown in Figures 13 and 14. Drawings such as these describe operation down to the plug-in-module level and are an indispensible aid in troubleshooting a problem.

193. Theory of operation. The theory behind the operation of the instrumentation as well as the controllers, and the system communications hardware was required as part of the system documentation. This information is necessary to familiarize the users and maintenance personnel with the functioning of all components. It included system specifications, hardware operating capabilities and limitations, as well as the operating theory of the components.

194. User documentation. As described beginning at paragraph 97, the system software was designed so that the user does not need to understand any complicated programming techniques. The documentation supporting this philosophy gives a step-by-step procedure for operating all the functions of the system including explanations of each of the on-screen help menus.

195. Maintenance documentation. Good maintenance documentation is necessary for the continued proper operation of the hardware. The maintenance personnel should have at their command all the maintenance schedules and system information to keep the system from breaking down; and if that should happen, possess the ability to quickly isolate the problem and find its solution. It was required that the documentation include schematic drawings of all components installed as part of the system. This will allow an independent repair technician or government repair personnel to service the equipment. All calibration procedures and tolerances for each component were included in the maintenance documentation to allow personnel to properly keep the sensors and measurement components of the system within acceptable accuracy tolerances. This included recommendations of the proper test equipment necessary

to perform these calibrations. A required part of the maintenance documentation was a complete list of replacement parts including a source for purchase of each such part.

196. Troubleshooting guide. As an additional aid in locating the source of trouble, a top-down troubleshooting guide was specified. This guide traces the symptoms of any trouble down to the replaceable card level, by asking a series of questions designed to lead the technician to the area of the trouble.

197. Training. The degree of training for personnel who will administer an automated instrumentation system is dependent on the size and complexity of the system. If the system is small, perhaps one that automates one type of instrument and does not have a complicated operating system, then the training can be modest. In that case, familiarization of the system could be accomplished by the instrumentation personnel by studying the system documentation. However, if the system is large or complicated, it is important to plan for the formal training of the operating personnel so that all the complex facets of the system are discussed and understood. It is a waste to purchase sophisticated capabilities only to have them ignored because the personnel do not understand them or know how to use them.

Instrumentation instruction

198. The instrumentation automation system installed at Beaver Dam is large in terms of the number of instruments which are automated, and is sophisticated as well in terms of the capabilities of the hardware and software. By virtue of the expandability of the MCU's and the complexity of the software which runs the controllers, it merited the attention of a formal instruction course taught by the designers of the system.

199. The instruction consisted of an 8-hr training session at the dam concentrating on the following topics:

a. Sensor and system installation

b. Sensor calibration

c. System operation

d. System maintenance

e. System troubleshooting

200. Instruction was given to all instrumentation personnel at the dam who would be involved with the operation of the system, and instruction space was included for several instrumentation personnel from the US Army Engineer

District, Little Rock, to attend. Each attendee was given a training document that covered the topics to be taught during the training session. It was also a summary of the capabilities of the system and a subset of the general operating manual.

PART IV: PLUMBLINE COMPARISON

Comparison of Automated Plumblines

Purpose

201. One facet of the instrumentation automation demonstration was to demonstrate the capability of measuring the movement of a plumbline by means of an automated monitoring system. This is a capability that has only been available in this country in recent years. The ability to do this requires a system to locate the plumbline in space, without adversely disturbing the functioning of the plumbline wire itself.

202. The technology that has been developed to automate the reading of a plumbline wire also helps demonstrate the principle of retrofitting existing instruments. For these reasons it was chosen as an additional portion of the demonstration program.

Scope

203. At the outset of the demonstration program, there were three US manufacturers of instruments that were capable of automating the reading of a plumbline. In choosing a location to mount this portion of the demonstration, the capability to compare as many of these instruments as possible was a prime consideration. Libby Dam, on the Kootenai River in the northwest corner of Montana, was chosen as the site to demonstrate this technology, because two of the three instruments that were manufactured to read plumblines were already installed on one plumbline at this dam. In order to provide a comparison of all three instruments, it was only necessary to install the third manufacturer's instrument on the same plumbline as the other two. This would allow not only a features comparison, but also a comparison of the precision of all three instruments responding to the movements of one plumbline.

204. During the installation of the third manufacturer's instrument, one of the the systems failed. Attempts to get the manufacturer to repair the equipment and participate in the comparison also failed, and this sensor system remained in a nonoperating condition and could not be evaluated. Rather than cancel this portion of the demonstration program, the comparison was made on the two remaining systems that were in operation and were being supported by their manufacturers. This made the comparison less complete, but still of value to the Corps of Engineers.

205. The comparison will encompass the features of the two remaining systems, a review of the operation of these systems, and a measurement comparison of their precision based on tests conducted at Libby Dam by WES.

Systems Descriptions

System A

206. Principle of operation. System A (a key is included in the front of this report to identify the system manufacturers) operates on the principle that the location of the plumbline wire in space can be identified by establishing the location of the shadow of the wire on two orthogonal banks of light receptors. The shadow is generated by directing parallel beams of light (forming a plane of light) across the plumbline wire. These parallel beams originate on one side of the plumbline wire and are detected on the opposite side by a bank of photodiode receptors. The location of the shadow within this bank of receptors establishes the location of the wire in one direction. The location in two-dimensional space is determined by using two banks of light beams and photodiode receptors.

207. System components. This system consists of three basic components: a sensor, a repeater, and a controller. At a minimum it must have at least one of each component, a fully saturated system can consist of as many as 12 sensors, a number of repeaters (which depend on the distance between the sensors and the controller), and one controller. Sensors and controller can be seen in Figure 33.

208. Description of the sensor. The sensor is built in a canister design measuring 9-1/2 in. outside diam, and 15 in. high. It was designed in this geometry so that the entire sensor unit could be fitted into the plumbline well either above or below the reading cutout, thus keeping the sensor out of the way of the conventional plumbline reading equipment which normally occupies the reading cutout. Since the standard plumbline well has a 10-in. diam, this sensor will fit the well in most instances.

209. Each sensor has two complete sensing axes to locate the wire in both the x and y directions. These axes are set up perpendicular to each other. Each axis uses twin banks of light emitting diodes (LED) as the light source. Two banks of LED's are used so that if one should fail, there will be a backup light source to continue reading the location of the wire. These

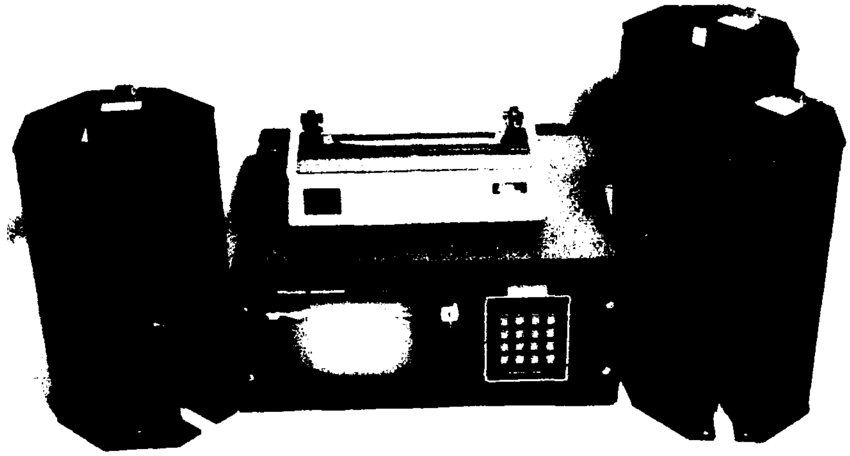
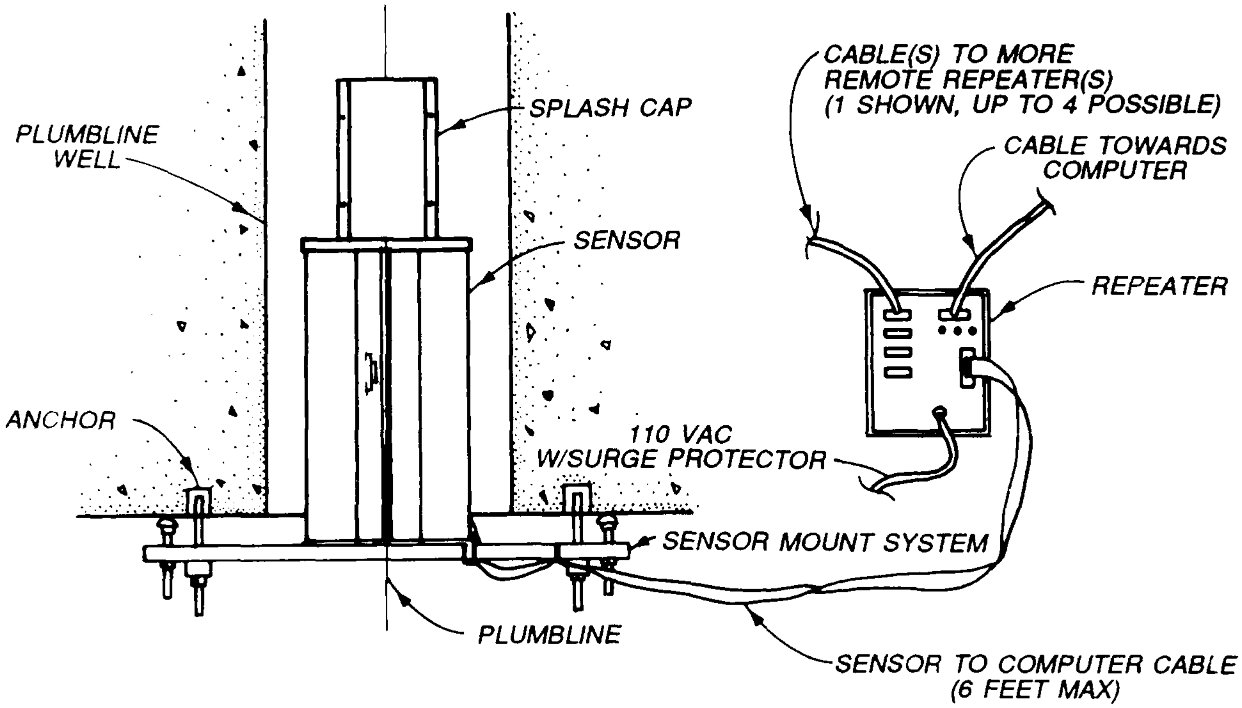


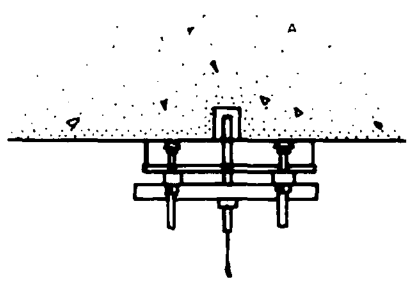
Figure 33. Central controller and three sensors of System A

light sources are passed through optical lenses and sent over a 40-in. light path before being directed across the path of the plumbline wire. After crossing the path of the wire, they are directed through another 40-in. path before reaching the photodiode receptor bank. The long light path is designed to ensure that the LED light that is passed across the plumbline is collimated or made to travel in parallel beams. This long path is achieved in a 15-in.-high canister by reflecting the light off mirrors in the top and bottom of the sensor housing.

210. The sensor unit fits around the plumbline and provides an internal 3- by 3-in. area in which the wire can move freely. The sensor housing is essentially octagonal, with four major sides. Two adjacent sides of the sensor house the light sources, and the other two sides house the photodiode receptor banks, providing the perpendicular reading axes that define the location of the wire. The sensor can be oriented in the plumbline well in any orientation that is convenient for the particular dam. Conversion equations that orient the output to upstream/downstream and left abutment/right abutment movement are provided in the controller. Figure 34 shows a drawing of the sensor installed above a typical reading cutout. The sensor mounting frame installs into the concrete on the roof of the cutout, and the sensor itself sits on top of its frame. Above the sensor is a splash cap, a chimney designed to prevent water from splashing on the optics of the sensor.



FRONT VIEW: SENSOR MOUNTING SYSTEM



SIDE VIEW: SENSOR MOUNTING SYSTEM

Figure 34. System A sensor installed in opening above plumbline cutout

211. The light source and optics within the sensor generate a 3-1/8-in.-wide beam of light focused onto the 512-element photodiode array on the opposite side of the plumbline from the light source. The 512 photodiodes produce a 3-in.-wide receptor field. Each photodiode receives a portion of the collimated light. Those diodes falling into the shadow of the plumbline receive only reduced or no light, thus identifying the location of the plumbline wire. The output of the photodiodes is interpreted as a set of voltage

levels and subsequently sent to the controller for analysis and spatial location of the plumbline wire.

212. The system is capable of output with measurement resolution down to 0.0001 in. This is achieved through the analysis of the data that is taken from the photodiodes. If the data coming from the photodiodes was just analyzed on a binary basis (1 indicating presence of light at a diode, 0 representing the absence of light), the resolution of the system would be only 0.006 in. However, the company utilizes a method of subpixel analysis to extend the resolution of the output to 0.0001 in.

213. Repeater. The system repeater is a component which is 5-1/3 in. wide by 6-7/8 in. high by 2-1/3 in. deep and contains a power transformer and circuitry to boost and pass signals between the sensor and controller. It accomplishes several chores, but its main function is to boost the strength of the signal as it travels between the sensor and the controller. The signal travels over an RS-232-C line, which is limited to transmission distances of approximately 1,500 ft before the signal must be boosted. The repeater receives the signal, decodes it, amplifies what it has decoded, encodes it again, and retransmits it along the line to the next repeater or to the controller. The use of a repeater system of signal transmission allows for transmission of many signals over long distances with a minimum amount of cable. Each sensor needs only a length of cable long enough to connect it to the nearest repeater.

214. The repeater is connected to the sensor unit through a ribbon cable assembly. This cable supplies power to the sensor and transfers data between system components. The repeater is the system component which is connected to standard 120-V AC. The power supplied is unregulated direct current which is then regulated in the sensor for each application. The sensor contains a +12 V regulator for each LED pair and a +15 and -15 V regulator for the detector electronics. In addition, the repeater acts as an interpreter of signals it receives from the controller. Each repeater in the system has a unique address, and if a command from the controller is intended for the repeater in question, it will pass that command onto its sensor. Otherwise, the command is passed onto the next repeater in line.

215. When a repeater recognizes a command intended for its sensor, it will turn on the light source in the sensor, take a reading, and pass the data gathered from the sensor back to the controller.

216. Controller. The controller is a dedicated computer housed in a rack mountable case. It is normally intended to be located in a central control room, such as a powerhouse, but can be rack mounted and enclosed in a NEMA enclosure for use in severe environments. The unit consists of a CRT display, a 16-key hexidecimal keypad, control circuitry, read only memory, RAM, a watchdog timer, battery operated clock, a modem card, and serial and parallel output ports. The controller is used to send commands to the sensors and to receive data from them. All commands to the sensors are given through menu-driven screens, and all output from the sensors is displayed on the CRT display, stored in memory, or sent to the system printer. Through the use of the modem card, the system can be controlled from remote locations and system output can be displayed at these remote terminals.

217. Operating menu. The controller is capable of a number of functions which all appear on the system operating menu. The operating menu can be accessed by pressing a 0 from any of the other menus described in the following paragraphs. These functions are displayed in Figure 35 as they appear on the CRT screen, and described in the following paragraphs.

OPERATING MENU

KEY

-0- OPERATING MENU

-1- PRINT DATA DISPLAY

-2- HISTORICAL GRAPHICS- BLK???

-3- CALIBRATION PROCEDURE

-4- LIVE TRACE- BLK???

-5- SET CLOCK AND INTERVAL

-6- MEASURE PLUMBLINES & OUTPUT

-7- RETURN TO NORMAL OPERATION

-F- RESET/POWER OFF & OUTPUT

Figure 35. Main menu of the controller screen

218. Print data display. When the controller requests a set of plumbline readings, the data that is returned to the controller is stored in the controllers internal RAM. When the print data display command is given, this last set of readings is displayed on the CRT or sent to the printer. The

DATA IDENTIFIER HEADING

DATE TIME

DATA- AUTOMATIC

BLK	RAD	TAN	S-R	S-L	DIA
01A	+0.0201	+0.2245	+0.020	+0.224	
01B	+1.9875	+2.9524	+1.954	+3.065	
12A	+2.2661	+3.1184	+2.157	+3.159	
12B	+0.1294	-0.0278	+2.158	+3.164	
12C	-0.8683	+5.0652	+2.155	+3.164	FOL

Figure 36. Print data display menu

standard display is as shown in Figure 36. The heading gives date, time, and whether the data being collected was from an automatic reading, an on demand reading, a reading subsequent to a power off condition, or requested from a remote terminal. The data headings S-R and S-L refer to sight right and sight left data. The RAD and TAN columns are the computed radial and tangential conversions of the S-R and S-L data. The BLK column is the identifier or repeater address that uniquely identifies the sensor providing the data. The column headed DIA is a diagnostic return telling the condition of the sensor. No entry in this field indicates everything is all right, while an F indicates that the optics are out of focus, an O indicates that the plumbline is out of range, and the L indicates an abnormal light level. The diagnostic in the above screen could suggest dirty optics or one of the two LED's had failed.

219. Historical graphics- BLK???. This function gives the user a view of the historical extremes of the plumbline travel coupled with a display of the present location of the line. The display that is produced is similar to the sketch shown in Figure 37. The outer four marks represent the historical limits for that plumbline location, and the inner mark shows the present location. The BLK??? is a reminder to the user to enter the block and gallery number (or other identifier chosen) for the sensor on which they want the historical data. This menu function has some value in allowing the user to see how close the present location is to the historical extremes. It acts merely as a reference.

220. Calibration procedure. This entry brings up a calibration menu.

```
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XXX                                  XXX
XXX                                  XXX
XXX                              0   XXX
XXX   0                              XXX
XXX                                  XXX
XXX                         0        XXX
XXX                                  XXX
XXX                                  XXX
XXX                             0    XXX
XXX 0                                XXX
XXX                                  XXX
XXX                                  XXX
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
```

Figure 37. Historical data display

Generally, this function is only used when a sensor has just been installed or has been relocated. It provides mathematical data for making coordinate transformations that provide correlation between the sensor measurements and the historical manual sighting measurement data.

221. Live Trace- BLK???. Executing this menu item brings up a graphics screen that shows the intensity of light being picked up by each photodiode in a particular bank of diodes. What it shows is a vertical line of dots on the screen representing the light intensity of the photodiodes on the axis chosen by the BLK??? entry. Most of the dots will be in a vertical line near the right side of the screen indicating high light intensities. However, those diodes partially shadowed or completely shadowed by the plumbline will indicate a lower intensity of received light by being displaced to the left of the screen an amount proportional to the reduction in intensity. This produces a curve with the location of the plumbline at the apex of the curve.

222. This function shows the location of the plumbline in relation to the rest of the photodiodes. It is a real-time display. That is, if the plumbline is moving it will show up on the screen as a moving curve. In this

respect this function has some usefulness in determining if the plumbline is still or moving. It could also be used to show if the plumbline is close to the edge of its photodiode range.

223. Set clock and interval. This function allows the user to set the controller to perform automatic readings of the plumblines on any desired schedule. The internal clock can be set through this menu to correct or adjust the time, the interval between automatic readings can be set here, and the date and time of day that the reading schedule should start is also a user defined parameter. The data entered under this menu is stored in battery backed memory so that if the power should fail the settings would not be lost, and when power was restored, the readings would continue on the automatic basis set before the power failure.

224. Measure plumblines and output. This feature allows an "on demand" scan of the plumblines. When this feature is chosen, the plumblines are read, the data in the memory buffer are updated, and the measurements are printed out on the printer.

225. Return to normal operation. This feature returns the system to the normal operation in which it monitors the RS-232 input, and takes readings of the plumblines on an automatic schedule. The RS-232 line allows input commands and output results to be sent to any remote source, such as another computer.

226. Reset/power off and output. This is a manual means of resetting the system. It turns the system off and on, reads all the system information stored in the battery backed nonvolatile memory to reset the parameters to those before the reset, and takes a "power off" reading of the plumblines. It then resumes with the normal automatic reading schedule.

227. Printer. The system is supplied with a Okidata 182P dot matrix printer with dot addressable graphics as the system printer. This allows all features of the CRT display to be saved as hardcopy.

228. Modem card. The system comes with an internal communications card that allows it to be accessed over standard phone lines. This provides for system access via modem, remote diagnostic problem solving, and remote system operation via a data acquisition system.

229. Operation via modem and most standard communication software packages allow two operations to be conducted. The user can read the last taken readings that are currently stored in nonvolatile memory or can request an

"on demand" set of readings be taken. The data given over the modem are the same as those given in the Print Data Display. None of the other displayable menu items are available via the modem.

230. The modem also allows the manufacturer to perform some remote diagnostic tests on the sensor and controller without having to make a site visit, or having the unit shipped to the factory. This can be a significant maintenance savings if the problem can be diagnosed over the phone.

System B

231. Principle of operation. System B works on the principle of a beam of light being moved through space and intersecting the plumbline wire to determine the location of the wire. An extremely narrow infrared light beam is sent from an emitter across the zone where the plumbline wire will be found. The beam of light is sensed by a detector on the opposite side of the instrument from the emitter. The emitter and detector are then translated laterally across the zone containing the plumbline wire by means of a motorized stage. The detector monitors the received light levels, and when the light intensity diminishes, the location of the plumbline wire is established. The emitter/detector passes a pair of reference wires located at the boundary of the measurement zone. The time that it takes to intersect these wires is a constant. These wires act as a calibration reference and also a baseline reference in locating the plumbline wire. As with System A, the plumbline wire is located in two-dimensional space by a second emitter/detector sensor located perpendicular to the first sensor.

232. System components. The system consists of two measurement units and a controller box. The measurement units each consist of an infrared emitter, a detector, an amplifier, and a precision motorized position stage. The controller box houses the output display and the controls which activate the sensors. Both the sensors and the controller box are housed in NEMA rated enclosures.

233. Sensors. Each sensor looks like a large tuning fork. They measure 12 in. wide, 11 in. deep, and 4 in. high. The arms of the this sensor straddle the plumbline wire as shown in Figure 38. When the two sensors are mounted one on top of the other, and at right angles, they define a horizontal window, 4 in. by 4 in., which is the measurement zone. The two arms of the sensor house the light emitter and the detector, while the base of the instrument houses the stepper motor which moves the emitter and collector. The

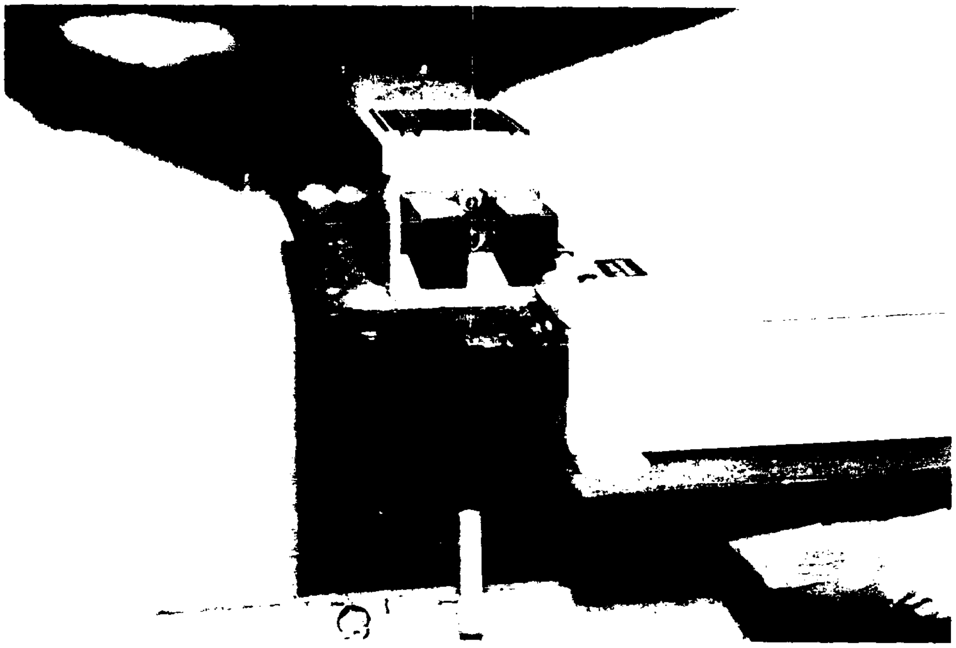


Figure 38. Two sensor units of System B

stepper motor moves the emitter/detector in 0.001 in. increments along the 4-in. run that defines the measurement zone. At each step, the detector is read, and the intensity of light being collected determines whether or not the sensor has sensed the presence of the plumbline wire. The process of reading each axis of the system takes about 10 min. This long reading time is a function of the number of times the sensor reads the position of the wire. The location of the wire is read many times, and before the location is reported, the average of the many location readings is taken. This average is the value which is reported to the controller. This is done to eliminate the effects of any swing or oscillatory motion which may be in the wire due to vibration or other motion of the wire. The sensor also detects if there is dirt on the glass between the emitter and collector and reports this as an error condition.

234. The sensors run on 12-V DC power which is obtained from the controller box. The connection to the controller box is by means of a nine-wire cable which carries power and command signals from the controller and delivers the output signal from the sensor back to the controller.

235. <u>Controller box.</u> The control unit is a NEMA 13 enclosure measuring 4 1/2 by 8 by 10 in. and houses the display, provides power and commands to the sensors, and contains the hardware and software that process the signals

from the sensors. The display is a single-line LED display that tells its status, and outputs the plumbline readings and other diagnostic information. The controller is shown in Figure 39. There are two control switches on the unit, the power switch and the function switch. The function switch is used to cycle the unit through its readings when the system is being read manually. The controller box also has output ports for a printer and a television (TV) screen. Beneath these output ports are the terminals for the controller power, input for the two axes of the sensors, and output to a data logger. The sensor shown at the top of the figure is one of those used at Libby Dam. The measurement head of the instrument is shown at the left of the photograph, and this model provides only for a measurement zone of 0.6 by 0.6 in. The newer sensors have the larger measurement zone.

236. When it is manually read at the plumbline station, the output display tells the system condition and the plumbline wire location. A typical cycle consists of the letter/number display sequence P1 through P5 and is described in the following paragraphs.

237. The user goes to the sensor and turns it on. This action initiates a reading of the plumbline. The room lights must be off while the system is making its measurement, because the light interferes with the mechanism for

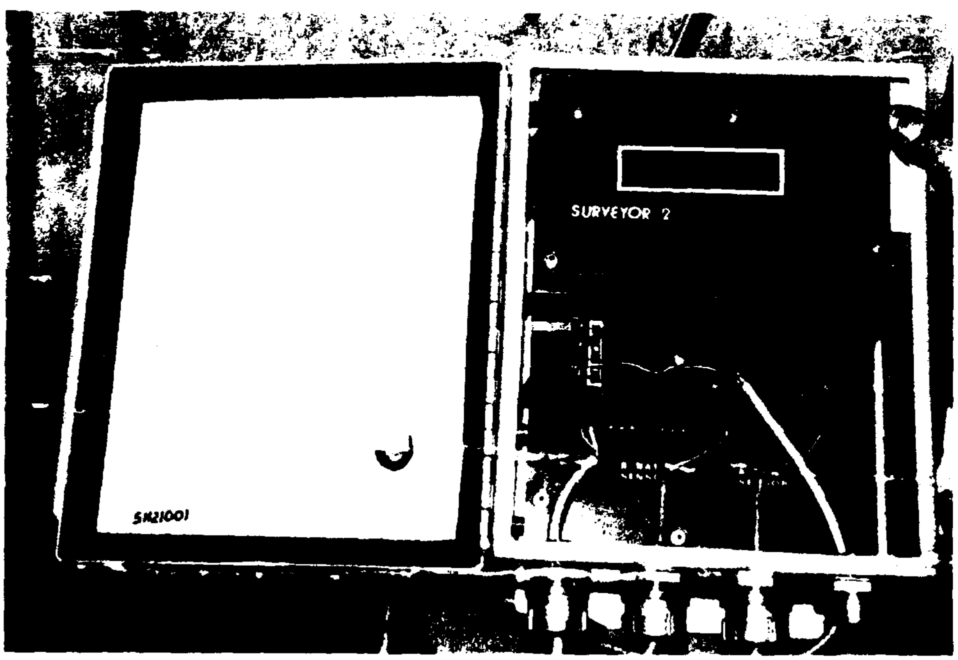


Figure 39. Controller unit of System B

reading the wire. After the power is turned on, the user has a period of about 15 sec to turn off the room lights. The display will show the prompt "P1" to indicate that it is time to turn out the lights. If the prompt "P2" should appear while the lights are still on, then the system should be shut off and the process repeated.

238. The prompt "P2" indicates the A-bar sensor is reading the location of the plumbline wire. There is about a 5-min delay during this operation while the A-bar sensor completes its readings of the wire location.

239. The prompt will change to "P3" when the B-bar sensor takes over the reading of the location of the wire. There will be another 5-min wait until this sensor has finished its readings.

240. The prompt "P4" signals when it is safe to turn on the lights in the room. The reading cycle is not yet complete, but the presence of light will no longer affect the sensor reading.

241. The "P5" prompt indicates that the readings are complete, and the data are being sent to the data logger, if one is interfaced to the system. This option allows the data to be sent to a logger or a PC system. With this capability, further reduction can be performed on the data, and the information can be sent to remote locations via a modem connected to the computer.

242. If a printer or a TV screen is hooked to the controller box, the output data will be sent to these devices, as well as being displayed on the single line display in the unit.

243. The display in the controller unit shows the A-bar plumbline output first. The characters that are displayed the farthest to the left of the line consist of three horizontal bars. If the top bar is lit, the number to the right of the bar is the A-bar reading. If the bottom bar is lit, the number is the B-bar reading. The center bar may be lit along with the top or bottom bar and indicates that the reading is negative. The output is measured in inches away from the center line of the measurement zone.

244. This display will remain until the function switch is pressed. When it is pressed, the display for the B-bar is shown. Its output appears the same as the A-bar reading.

245. Pressing the function switch again will show a window cleanliness diagnostic. An indication of "00" tells that both sensor axis windows are clean, "01" indicates dirt on the B-bar window, "10" indicates dirt on the A-bar window, and "11" indicates both windows are dirty.

246. Another press of the function switch will give another combination of ones or zeros which will tell if the sensors are functioning properly. "00" indicates both axes are properly calibrated and measuring properly, "01" indicates trouble with the B axis, "10" the A axis, and "11" trouble with both axes.

247. There are seven additional diagnostic messages that will appear when the function switch is pressed the next seven times. These diagnostics are used by the manufacturer to pinpoint any problems in the system. After all diagnostics have been displayed, the output line again displays the A-bar plumbline position. To take measurements of the plumbline again, turn the power to the system off and then back on.

248. Optional readout. An optional stand-alone readout device that can display 80 characters by 24 lines of output is offered by the company. It operates on 12-V DC battery or AC line current, has a full keyboard, clock calendar, and printer output. Options that can be added to this device include a printer, external data storage device, and telephone modem.

Operational Comparison

Comparison factors

249. Sensor location. Under normal conditions, the physical location of the sensor will not be a significant consideration; however, since the two systems differ in the location of the sensor, they should be discussed. System A puts the sensor up (or down) in the plumbline shaft out of the way of activity in the reading cutout. System B installs the two sensors on top of the existing frame which is normally part of the plumbline manual reading system. Putting the sensor out of the way makes the reading cutout less cluttered, and there is less possibility of accidentally hitting the sensor and moving its axes. However, because the sensor is out of the way it is more difficult to get to if it is necessary to replace or clean a part. System B is very accessible because it is directly over the manual reading apparatus, but it can possibly get in the way if manual readings are made very often.

250. Sensor reading ease. The physical reading of plumbline wires is done automatically by both systems. Both systems also can be configured to automatically read the plumbline on a regular schedule, and print or display the output. System A provides the computer hardware to automate the reading

as part of the basic package. System B relies on the previous existence of computer hardware to control the automatic reading of the sensor, and provides the manual controller box and sensors with the basic system. The latter is convenient and economical when there is a data acquisition system available. However, if the plumbline monitoring equipment is installed as a stand-alone item, a user must activate the sensors each time a reading is to take place. This can be done automatically by installing the system on a timer circuit which will shut power off and then on, and at the same time shut off any lights that are in the reading room. The interruption of power to the system causes it to take a reading when power is returned to the controller.

Systems A and B locations

251. In the setup at Libby Dam, the controller for System A was located in the instrumentation office, and the controller for System B was mounted by the sensor in the reading cutout. All sensors connected to System A could be read from the one central controller without going to the reading cutout. To read the output of System B it was necessary to go to the reading cutout to activate the system. This could be advantageous if one were making comparisons between the automated readout and the manual readings and the person reading the instrument had to go to the cutout to manually read the plumbline. On a regular basis, reading the output at the readout station is no more convenient than the manual method. If System B is used, it is recommended that it be used in conjunction with an automated data acquisition system or the makeshift timing circuitry.

252. The reading speed of the two systems is dramatically different. System A makes its readings in a matter of 1 or 2 sec, while it takes System B approximately 15 min to read the two axes of the plumbline wire. There are two reasons for the difference in speed of reading. System A makes only one reading, and it is made at electronic speeds (fractions of a second). System B makes multiple readings of each axis, and makes them at a speed compatible with the speed of the stepper-motor driven stage. The speed of the reading is not an important element when either system is being read automatically, and the user does not have to wait for the output. However, if an on-demand reading is needed, or the user is using System B in the manual mode, the waiting time is annoying.

253. The System B technique of reading the plumbline numerous times and averaging the collected data will minimize any erroneous readings which may be

recorded due to movement of the plumbline wire. If there should be any movement of the wire and System A read the location of the wire at an extreme of the movement, there could be significant error in the output. One of the display features of System A, however, is the real-time display of any movement of the wire. If wire movement is suspected, it can be displayed on this screen and monitored until it stops before taking a reading.

254. As previously discussed in the system description sections, System A provides a greater amount of information from the system than does System B. Under automated conditions, both systems will provide the location of the plumbline wire. This being the major function of the automated plumbline system, both systems are put on an equal footing regarding the time-dependent monitoring of the wire. However, if data are being monitored on a demand basis and there is need to do comparison work, System A provides greater flexibility for obtaining information about historical data and live trace information. Neither system, when operated alone, can provide for the need of setting an alarm if measurements are outside a desired area. However, if these systems are part of a larger data acquisition system, the parent system can provide for this need.

Measurement Comparison

Technical aspects

255. Since both systems were installed on the same plumbline, a comparison of their precision was feasible. An in-place test was designed to determine the precision of both systems against a calibrated standard and to make a comparison of the precision between systems.

256. Measurement standard. To make these comparisons, it was necessary to find a standard of moving the plumbline a known distance, read both sensors, and record the data received. This was not an easy task, since the test could not be conducted under laboratory conditions. The best in-place method was to devise a system that would move the plumbline with an acceptable degree of control over the precision of the moving mechanism. It was also an important consideration to test the two systems over the maximum range that conditions would allow to see whether precisions reported were consistent over the total range of their reading zones.

257. The best solution to this field measurement problem was to

immobilize the wire with respect to a set of orthogonal axes and then control the movement of the wire in relation to these axes. This was accomplished by connecting a two-axis stage to the plumbline wire, in which the movement of each axis of the stage is controlled by a micrometer.

258. In choosing any system to precisely move an object, there will be some amount of error due to the fact that the system chosen will have a measurement system to record the amount of movement, and will be subject to errors induced by that system. This is particularly true when the measurements must be conducted at a field site. Additionally, the movement of the stage mechanism itself had to be prevented so that any movement imparted to the wire would be a known movement in the x and y directions due only to the movement of the micrometer driving the particular axis of the stage mechanism. Finally, the movement mechanism had to be mounted above all the recording instruments to ensure that each instrument saw the same amount of movement of the wire.

259. A photograph of the stage is shown in Figure 40. The stage consists of two platforms, one for each axis of movement. The two platforms are

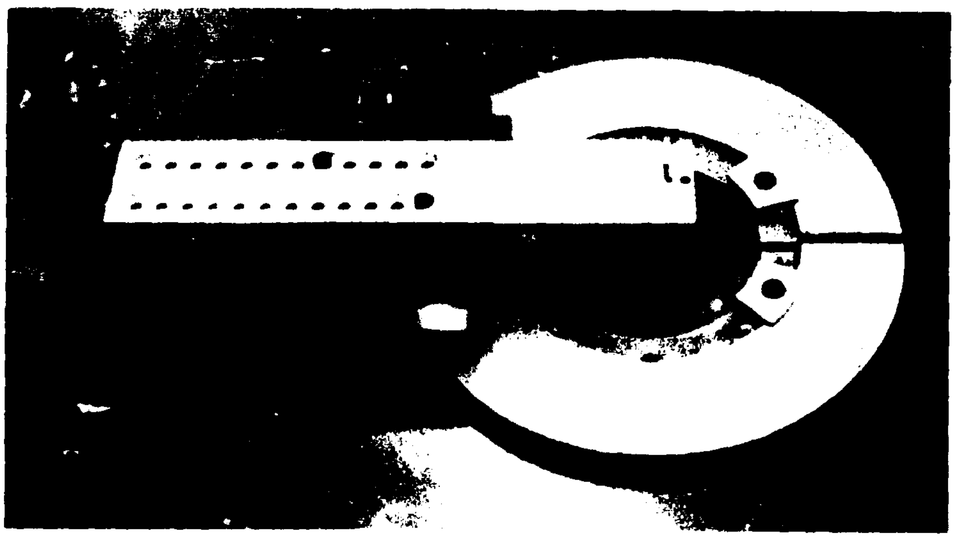


Figure 40. X-Y stage used to move the plumbline wire during the comparison tests

mounted one on top of the other, so that if the upper platform is moved, it moves by itself; but if the lower platform is moved, the upper one moves along with it. Each platform is driven by a micrometer with least divisional reading of 0.001 in. An arm on the upper stage is designed to attach to the plumbline wire and move the wire the same amount and direction that the platforms are moved. The stage is set in a ring type frame that can be mounted to any stable surface. In this case, the stable surface was the frame on which one of the plumbline monitoring systems was mounted. This frame was the most stable structure in the reading cutout, and was substantial enough in cross section that the stage itself did not move during the comparison.

260. The two platforms can rotate within the ring to allow orientation of the two orthogonal axes to any desired direction. The axes were aligned to coincide with the directions of the x- and y-bar directions used in the manual reading of the plumbline (at 45 deg to the main axis of the dam). When the direction was determined, the ring mechanism was immobilized.

261. Measurement range and grid. The System B sensors installed at Libby Dam were that manufacturer's older sensors. Where the sensor that is now being manufactured has a 4-in. range, the sensors that were installed had a 0.5-in. range. When two of these sensors were combined so that the plumbline could be read in two directions, the resulting area over which the plumbline wire could move was restricted to 0.36 sq in. As a result, the area over which the comparison could be performed was limited to this area.

262. For the comparison purposes, it was decided that the plumbline wire would be moved a total distance of 0.375 in., in increments of 0.125 in., in both the x- and y-axis directions. This would make a grid of 16 points where measurements would be taken. This grid is shown in Figure 41. A photograph of the sensor and automation equipment for both systems is shown in Figure 42.

Measurement procedure

263. The procedure for making the measurement was as follows. A base reading for both sensors was made at one of the interior points (point 0) of the 0.375- by 0.375-in. square grid. The plumbline was then moved 0.125 in. along the x axis and 0.125 in. along the y axis to establish point 1 at one of the corners of the grid. The plumbline was allowed time to settle, and stop its pendulation before the reading for point 1 was made. The real-time trace capability of system A was employed to determine when the plumbline had stopped moving. A reading was taken on point 1, and a similar procedure, moving 0.375 in. along each axis, was used to establish point 2 at the opposite corner of the grid. In a like manner, the two remaining corners, points 3 and 4, were established, and the remaining peripheral and interior points were taken in numerical order as shown in Figure 40. Each new point was obtained

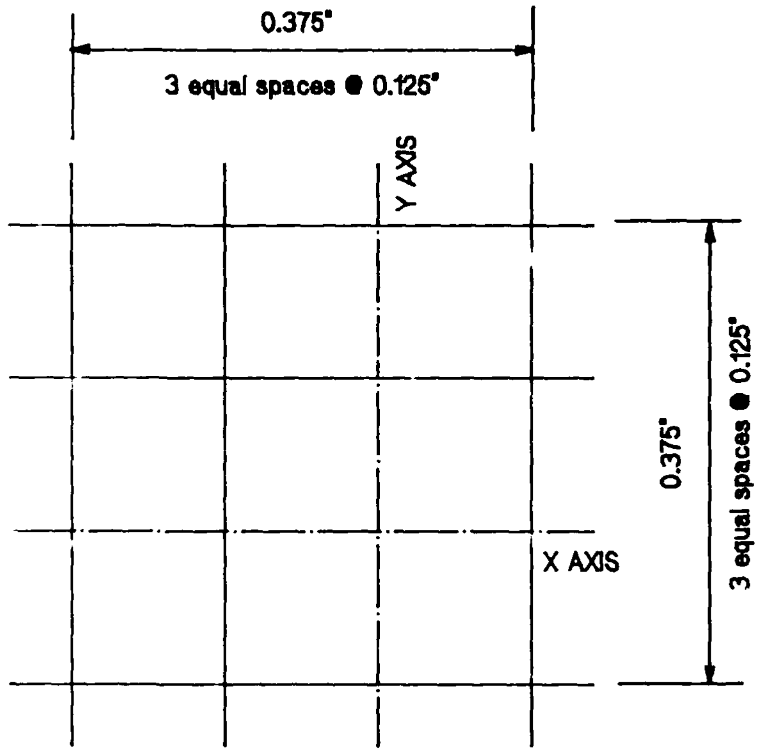


Figure 41. Grid used in comparison of plumbline reading systems

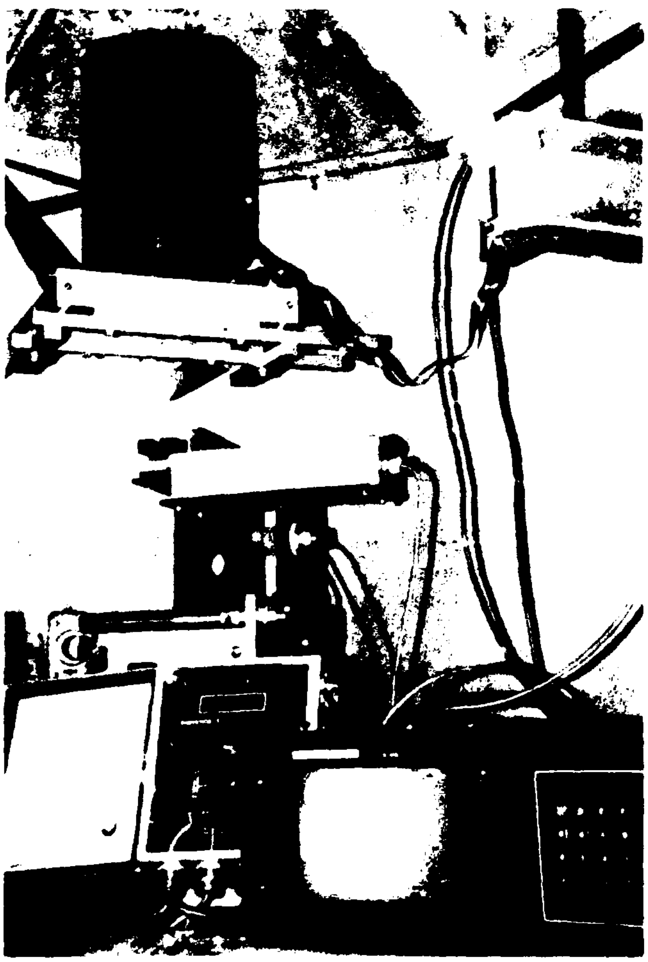


Figure 42. Setup of sensors and readout equipment for the plumbline comparisons

by moving the micrometers exactly 0.125 in. on each axis from the previous point.

264. Twenty-four measurements were produced from measuring the distances between each of the 16 grid points. The raw data from this test is given in Appendix A. The reduced data, giving the measured distances between grid points, have been superimposed on the grid shown in Figure 43. The value reported above or to the right of the line between any two points refers to the distance reported by System A, while those below or to the left are from System B. Referring to the raw data in Appendix A, the data reported for System B is given to the fourth decimal place, and those for System A are given to the third. Both systems calculate the location of the plumbline to the fourth decimal place (reflecting the measurement resolution of 0.0001 in.); however, System B displays it to the fourth decimal, and System A rounds its display data to the third decimal. For purposes of this comparison, the System B data was rounded to the third decimal before calculations were made on either set of data in order to make the comparison equitable.

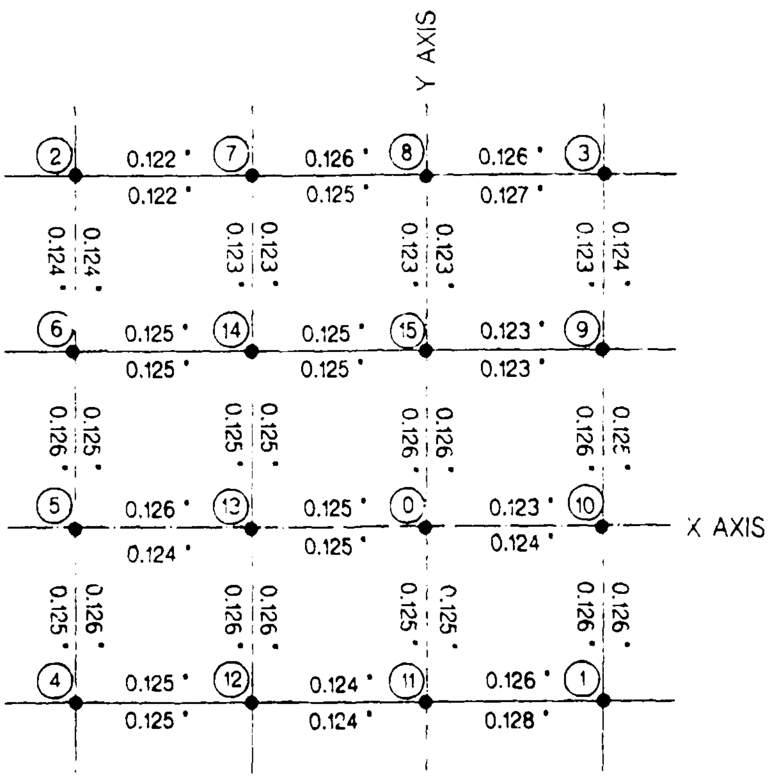


Figure 43. Comparison of movement readings for Systems A and B

265. Comparison results. The results of the comparison displayed in Figure 43 are tabulated in Table 2. Of the 24 measurements, both systems gave the same precision 15 times with a 16th measurement being equally precise, but the measurements themselves being of opposite sign. On five of the readings, System A was considered more precise when compared at the third decimal, and on three of the readings, System B was more precise when compared at the third decimal. All readings taken were within 0.003 in. of the 0.125 in. the platen was moved. Both systems produced readings which equaled 0.125 in. in one third of the measurements. These results do not support either manufacturers' claims of precision equal to 0.001 in.

266. Precision of the measurement stage. The x-y stage which was used to move the plumbline was checked for its precision by mounting the stage on a milling machine at WES, and checking the precision of movement with a dial gage with least reading of 0.0001 in. The greatest error recorded in tests of the platform was 0.0005 in., indicating that the wire movement between each measurement point using the micrometers was between 0.1245 in. and 0.1255 in. for each 0.125-in. movement of the micrometer.

Cost Comparison

267. It is difficult to accurately compare costs between these two systems, because they are so different in physical make-up and measurement philosophy; however, in the interest of completely describing these pieces of equipment, cost should not be omitted. These costs were obtained from the manufacturers in November of 1987, and were current as of that time. Due to the volatility of prices in the instrumentation and electronics fields and publication timeframes, the following information should only be used for comparison purposes.

268. Each of the systems can handle a number of sensors without having to add another controller unit. As such, the per-sensor cost of an overall system will go down as the number of sensors goes up. This is true for both systems. For the purposes of comparing the costs of these two systems, they will be configured with one controller each, two sensor units each capable of monitoring both x- and y-axis movement, and automation equipment that will allow both systems to be remotely monitored from within the dam, i.e., from the powerhouse and from a district or division office via modem communication.

Table 2

Tabular Comparison of the Data from Systems A and B

Distance Between Points	Difference from 0.125 in. System A	Difference from 0.125 in. System B	More Precise System System A	More Precise System System B
X Axis				
2-7	-0.003	-0.003	SAME	
7-8	+0.001	+0.000		X
8-3	+0.001	+0.002	X	
6-14	+0.000	+0.000	SAME	
14-15	+0.000	+0.000	SAME	
15-9	-0.002	-0.002	SAME	
5-13	+0.001	-0.001	SAME*	
13-0	+0.000	+0.000	SAME	
0-10	-0.002	-0.001		X
4-12	+0.000	+0.000	SAME	
12-11	-0.001	-0.001	SAME	
11-1	+0.001	+0.003	X	
Y Axis				
3-9	-0.001	-0.002	X	
9-10	+0.000	+0.001	X	
10-1	+0.001	+0.001	SAME	
8-15	-0.002	-0.002	SAME	
15-0	+0.001	+0.001	SAME	
0-11	+0.000	+0.000	SAME	
7-14	-0.002	-0.002	SAME	
14-13	+0.000	+0.000	SAME	
13-12	+0.001	+0.001	SAME	
2-6	-0.001	-0.001	SAME	
6-5	+0.000	+0.001	X	
5-4	+0.001	+0.000		X

* Precision the same, measurements were of different sign.

There are several costs that are dependent on the installation location, namely the wire and hardware costs and the installation costs. Since these do depend on the location and size of the system, they will be eliminated from the cost comparison.

269. A configuration of System A, consisting of two sensors (both measuring x and y axes), two repeater units, one central controller with real-time clock and modem card, and a printer, was quoted at $27,840 excluding installation and wiring. A similar configuration of System B, consisting of four sensor units (each measuring one axis, for a total of two complete x- and y-axis units), one local readout box, and one remote computer unit consisting of a model 3401 master control module, a model 3489 uninterruptible power supply, model 3422 modem, model 3432 analog input module, model 3453 RS232-RS422 converter, all in a NEMA type 4 enclosure for remote monitoring, was quoted at $34,955.

270. Excluding hardware and installation expenses, these configurations are not completely comparable. It should be pointed out that System A is a stand-alone plumbline monitoring system and is designed only for that purpose. In the remote reading configuration, System B will also be capable of accepting input from sensors other than plumbline monitoring equipment and can be used as a data acquisition system.

271. The installation and wiring of both these systems should be accomplished by their respective manufacturers. They are very sensitive pieces of equipment, needing precise installation adjustments to ensure precise reading of the plumblines. The manufacturers are trained to do this quickly, efficiently, and will guarantee that the work is installed correctly.

PART V: CONCLUSIONS AND RECOMMENDATIONS

272. At the outset of this program, the objectives of the work unit were to improve the instrumentation used to collect data at Corps projects as well as to enhance the capability to collect these data. It was also noted that there is an emerging instrumentation technology that allows automation of the tasks of data collection at a cost which is affordable to the general instrumentation community. To implement the benefits of these statements and aims was the primary goal of this work unit.

273. The installation of a major data acquisition system at Beaver Dam supported these ends. This system, which automated the reading of over 80 piezometers, 9 weirs, 20 uplift pressure gages, the movement of 2 cracks in the monolith walls of the dam, and both headwater and tailwater elevations, demonstrates the ability to bring electronic instrumentation and civil engineering sensors together to act as a unit to improve data monitoring and collecting techniques.

274. The frequency at which these instruments now can be monitored is testament to the improvement of the overall instrumentation monitoring capability that automation offers to the Corps. Under this demonstration it was shown that tasks such as reading the 80 piezometers, which formerly would take a team of field personnel 4 hr to complete, can now be completed in less than 1 min. This 240-fold decrease in data collection time not only allows field personnel to devote their efforts to more critical tasks such as concentrating on maintenance and repair tasks and processing paper work more efficiently, it also means that data can be collected on a more frequent basis. This is particularly important when physical parameters are changing at a rapid rate, and it is important to know these changing values.

275. The addition of automated reading equipment provides a reading constancy that is difficult to achieve under manual means. A well-tuned sensor measures a condition in the same manner every time. Human technique often allows variation to enter into the measurement process; whether it comes in the form of variation due to different personnel reading the same instrument or from the changes in an individuals sensitivity for reading the instrument. The elimination of just this one variation can immensely improve the quality of output. While people will always be critical to the interpretation

of the meaning of data, the use of automated reading equipment will mean that the data they interpret can be of better quality.

276. The automation of instrumentation, such as headwater and tailwater sensors and uplift pressure pipes by the addition of electronic sensors, provides new and innovative means to improve the quality of instrumentation data without having to completely rebuild the capability. This retrofitting methodology provides improved capabilities at the lowest cost. Since many of the Corps' structures are already instrumented, it is easier and more economical to retrofit these instruments for automatic monitoring than to install all new equipment.

277. It can be concluded that the automation of the structural and geotechnical instrumentation at Beaver Dam has been a successful venture. The quantity and quality of the data being collected has increased, the data are reduced and displayed on a more rapid schedule, and critical monitoring tasks are now watched on a more frequent basis.

278. For the future, it is recommended that the initiative to develop and install safety related automated instrumentation at Corps projects be expanded. The ability to automate instrumentation monitoring at a reasonable cost is new, and the technology is rapidly changing. Capabilities which were not available only 10 years ago are now rapidly becoming obsolete, and new and more capable options in both hardware and software are being developed daily.

279. From the hardware point of view, improvements in areas such as development of surface and internal crack monitoring instrumentation for concrete structures are needed. New techniques to monitor the plumb and tilt of structure need to be developed to reduce the cost of automation of these tasks. Better techniques of hardening electronics to the harsh environments of civil engineering projects will ensure longer times between instrumentation failures.

280. Improvements in software to reduce and display the data which are being collected are needed. It is recommended that standards be set within the Corps that will allow for easy transfer of data among users and computers. This will facilitate the sharing of information and techniques to reduce and display it. While the present state of the art in information presentation is a good start, supervision and control software need to be designed to make the user more comfortable in using it.

281. Finally, the most important element in the data acquisition chain,

the user needs to embrace the new technology and understand that it can be used to greatly improve productivity, data quality, and safety of our structures.

APPENDIX A: RAW DATA COLLECTED FROM PLUMBLINE SYSTEMS A AND B

	System A		System B	
Grid Point	Y-Axis	X-Axis	Y-Axis	X-Axis
1	+0.321	+0.871	-0.1021	-0.1276
2	+0.690	+0.498	+0.2567	+0.2485
3	+0.696	+0.872	+0.2729	-0.1259
4	+0.315	+0.496	-0.1185	+0.2491
5	+0.441	+0.496	+0.0065	+0.2482
6	+0.566	+0.497	+0.1327	+0.2489
7	+0.693	+0.620	+0.2628	+0.1263
8	+0.695	+0.746	+0.2689	+0.0009
9	+0.572	+0.870	+0.1497	-0.1246
10	+0.447	+0.870	+0.0239	-0.1248
11	+0.321	+0.745	-0.1059	-0.0001
12	+0.319	+0.621	-0.1113	+0.1241
13	+0.445	+0.622	+0.0148	+0.1240
14	+0.570	+0.622	+0.1399	+0.1239
15	+0.572	+0.747	+0.1456	-0.0015
16	+0.446	+0.747	+0.0195	-0.0013

NOTES: Each entry represents data given by that system when the plumbline was read.

To relate raw data to Figure 43 in the text, find the difference between the grid points for the axis desired.

Example: Between grid points 2 and 7 in the X-axis direction, the measurement distance for System A is 0.122 in., or 0.620 - 0.498 = 0.122.